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PRELIMINARY DESIGN STUDY OXIDIZER TANK RELIEF VALVE FLOX-ATLAS AIRBORNE

BY

D. L. GRAY, C. W. AULGUR & A. M. COLVIN

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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NOTICE

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PRELIMINARY DESIGN STUDY

OXIDIZER TANK RELIEF VALVE

FLOX-ATLAS AIRBORNE

FINAL REPORT

GD/C-BJB65-009

21 SEPTEMBER 1965

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FOREWORD

This report, containing the results of a preliminary design study sponsored by the National Aeronautics and Space Administration, was prepared under General Dynamics/Convair TCP 8459 in compliance with Contract Number NAS3-3245, Task Order Number 5 and Supplemental Technical Direction Number 2.

ABSTRACT

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Two separate design philosophies for protecting the FLOX-Atlas oxidizer tank against overpressurization were studied. One approach, the use of the boiloff valve for venting at a high pressure, was abandoned when extensive modifications became apparent. The second system of adding a smaller (2 3/4 line size) valve for relief at maximum tank pressure proved to be more acceptable. Three different designs were studied and one was recommended for use.

author

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INTRODUCTION

General Dynamics/Convair and NASA have established the feasibility of using FLOX as an oxidizer to increase the performance capability of the Atlas Space Launch Vehicle.

The present Atlas configuration requires a close tolerance pneumatic pressurization system to maintain structural integrity of the propellant tanks. This close tolerance pressure must be maintained with airborne equipment from two minutes prior to lift-off (internal pneumatics) until payload staging. During this period, the possibility exists that overpressurization of the oxidizer tank can occur from two major sources; failed regulator which is most critical during the first few seconds of internal pneumatics (because of small ullage and high inlet pressure) and/or increasing pressure caused by vaporization, during the latter portion of the flight. These inherent conditions require that the oxidizer tank be equipped with an inflight relief system to prevent tank rupture and possible mission failure.

Two preliminary design concepts of an airborne FLOX-Atlas oxidizer tank relief system are covered in this study. Section I of the study investigates the use of the present GD/C Atlas Oxidizer 12-inch Boiloff Valve (P/N 55-80209) as a FLOX tank airborne relief valve. This investigation assumed no modification to the present valve except for the addition of an airborne relief valve controller with all metallic parts and elimination of all "soft goods" in the present low pressure (ground) controller. Section II of the study investigates new relief valve designs employing only metallic bellows, diaphragms, poppets or other metallic seals.

Both relief concepts are designed and/or evaluated to meet the airborne FLOX-Atlas Oxidizer Tank Relief Valve Performance Specification. This performance specification, established as part of the study, is included in this report as Attachment 'A'.

The designs presented are based on current technology as determined through limited research and numerous vendor contacts. A state of the art survey was made at the beginning of the study. Reports of previous efforts to design metal to metal seals were studied. Various companies were contacted and/or visited to obtain information associated with relief valves utilizing metal to metal seal designs.

The following personnel were contacted during the study effort and were particularly helpful.

R. L. Kenyon	Parker Aircraft Company
G. Armstrong	Flexonics
F. Orona	Fluidgenics
R. M. Hamilton	Robertshaw-Fulton
N. Woolgar	B. H. Hadley, Inc.
B. Hadley	Demcor, Inc.
R. Smith	STL
R. Summers	Calmec

SUMMARY

The design study for adding a controller to the present GD/C boil-off valve indicated that it is not feasible to use the present valve as a FLOX tank airborne relief valve.

The all metal relief valve study indicated that the most logical and technically sound device for a FLOX application was a rupture disc, with a positive mechanical rupture mechanism, upstream of a simple spring-loaded poppet type relief valve.

SECTION I

USE OF PART NO. 55-80209 AS AN AIRBORNE RELIEF VALVE

OBJECTIVE

The objective of this study was to investigate the present GD/C boil-off valve configuration to determine if the valve function could be modified to meet the requirements of the Airborne FLOX-Atlas Oxidizer Tank Relief Valve Performance Specification by adding an additional controller.

CONCLUSIONS

1. It is not feasible, without extensive redesign, to use the present boil-off valve (P/N 55-80209) as a FLOX tank airborne relief valve by adding an inflight controller actuated by tank pressure.

2. The present boil-off valve could be redesigned for use as an airborne relief valve by eliminating the inherent instability and adding a separate external pressure source and/or electrical solenoid for controller actuation. A bi-stable controller operation approach would be most practical for accomplishing minimum leakage, fast response, and limited main valve poppet stroke.

DESCRIPTION OF OPERATION

The present boil-off valve (BOV) consists of a bellows section and a 3-way controller similar to the valve and controller shown in Figure I.

When the tank pressure is below the controller set point pressure, the controller vent port is closed and the supply port is open. This allows pressure in the BOV bellows section to be equalized with the tank pressure. Due to the initial BOV bellows preload and the differential area of the BOV bellows section exposed to tank pressure, the valve remains closed. When the tank pressure exceeds the set point pressure, the controller bellows compresses, closing the supply port and opening the vent port. The BOV bellows section is then isolated from the tank and vented to atmosphere. When there is sufficient differential pressure between the BOV bellows section and the tank ullage, the tank pressure on the exposed seat area compresses the BOV bellows section, allowing the tank to vent. When the tank pressure decreases below the controller set point pressure, the controller bellows expands closing the vent port and opening the supply port. This allows gas to flow from the tank into the BOV bellows section. The BOV will reseat when the tank pressure has been reduced to the point where the spring force of the bellows and the force due to bellows internal pressure becomes greater than the force produced by the tank pressure on the exposed seat area. This controller operates at standby pressure and closes off at higher pressure.

The addition of a similar controller was considered for the relief mode operation, and would actuate when the pressure rose to the high set point.

PERFORMANCE REQUIREMENTS

The relief valve controller and BOV shall be capable of meeting the requirements of the performance specification while operating with a fluid medium of liquid or gaseous oxygen and/or liquid and gaseous fluorine in any mixture ratio. The performance specifications are shown in Attachment 'A' as the -1 configuration.

The pressure relief performance requirements of the unit are as follows:

1. Reseat pressure, 32.1 psig minimum.

2. Full flow pressure, 34.7 psig maximum.

3. Full flow rate, 0.80#/sec of helium at 150°F and 34.7 psig.

4. Tank ullage, 25 ft^3 minimum.

The relief valve controller and BOV are required to operate when exposed to fluid temperatures from -300°F to +450°F. The relief valve controller must operate the 12 inch BOV within the above tank ullage pressure requirements.

The airborne relief function is required to operate automatically until after payload staging. The pressurization helium supply is jettisoned at booster engine cutoff, therefore, tank pressure is the only pressure source available for inflight valve actuation.

PERFORMANCE ANALYSIS

The following performance calculations are based on the BOV dimensions shown in Figure I.

Flow Capacity

The BOV bellows effective areas, volume and operating characteristics are:

A_E, exposed area $= \frac{\pi}{4}\left[15.75^2 - 12.25^2\right] = 77\ IN^2$

A_1, internal area $= \frac{\pi}{4}\left[15.75^2 - 11.75^2\right] = 86.5\ IN^2$

V_1, volume $= A_1 h = 86.5\ (6.1) = 527\ IN^3$

Spring rate of bellows assy. = 140 #/IN.

Initial Preload = 300#

Valve Capacity = 15 #/SEC O_2 @ 12.0 PSIG - 290°F

Valve Travel = .60 IN. MAX.

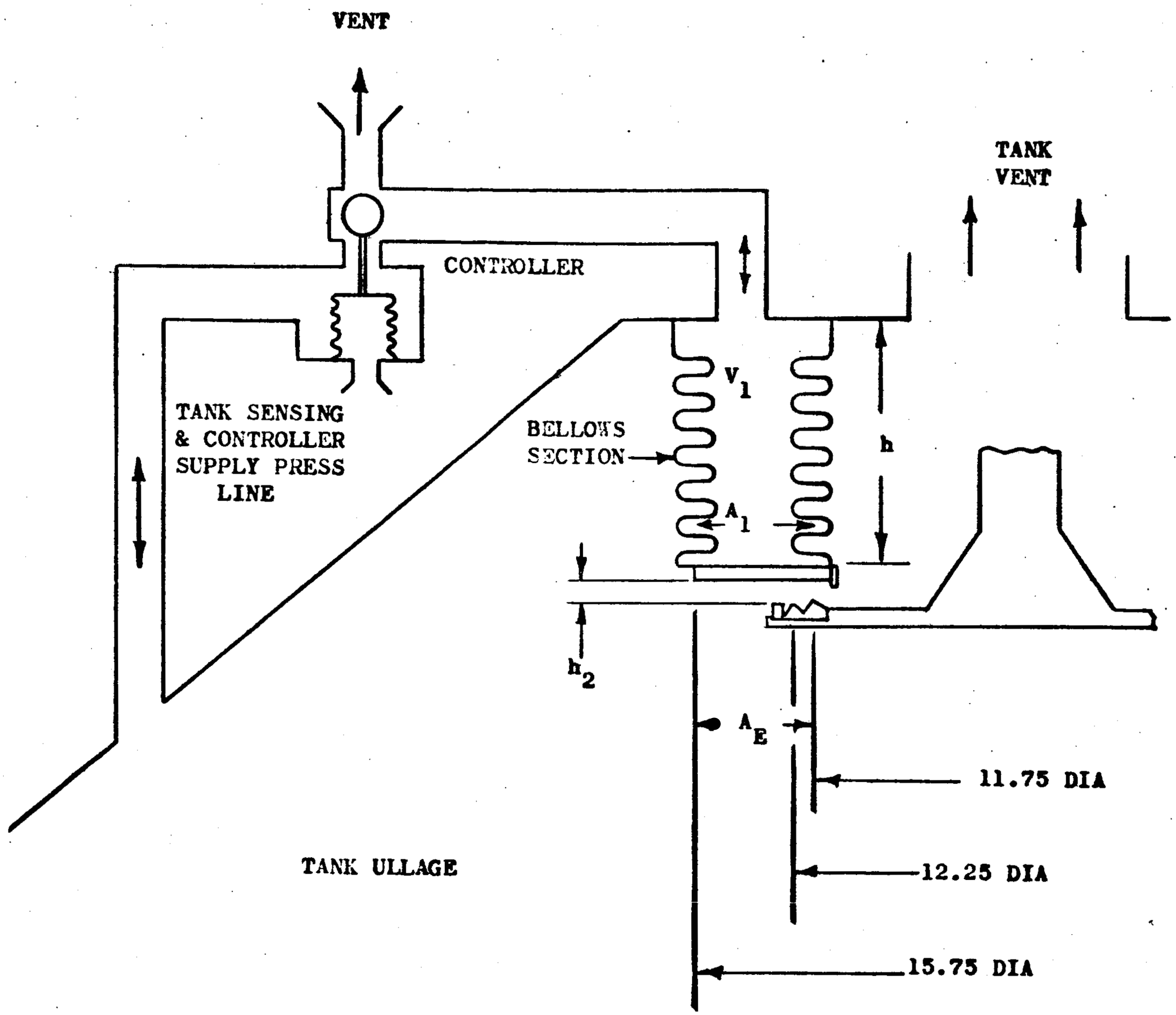

VENT
TANK
VENT
CONTROLLER
TANK SENSING
& CONTROLLER
SUPPLY PRESS
LINE
V_1
BELLOWS
SECTION
h
A_1
h_2
A_E
11.75 DIA
12.25 DIA
15.75 DIA
TANK ULLAGE

FIGURE I

Flow Capacity (cont'd)

The required flow area of the valve is based on a flow capacity 10% greater than the required helium flow rate of .80#/SEC (inlet gas pressure at 34.7 psig and 150°F). Based on the orifice flow equation, the required valve flow is:

$$\text{Area} = \frac{W}{cKY\rho_1}\left[2g\,\frac{P_1 - P_c}{\rho_1}\right]^{-1/2}$$

Where
W = .88#/SEC - Flow Rate
ρ_1 = .0290#/FT^3 - Density @ 49.4 PSIA @ 150°F
P_1 = 34.7 PSIG = 49.4 PSIA - Inlet Pressure
P_c = .486XP_1 - Critical Pressure
KY = C_D = .5 (ASSUMED) - Combined Flow Coefficient
g = 32.2 FT/SEC^2 - Acceleration of Gravity
c = 1.058 - Flow Correction for Super Critical Flow

For Helium

$$\frac{P_c}{P_1} = .486$$

$$P_c = .486\ (49.4) = 24.0\ \text{PSIA}$$

$$P_1 - P_c = 49.4 - 24.0 = 25.4\ \text{PSIA}$$

$$\text{Area} = \frac{.88\ \frac{\#}{\text{SEC}}}{1.058 \times .5 \times .0290\ \frac{\#}{\text{FT}^3}}\left[64.4\ \frac{\text{FT}}{\text{SEC}^2}\ \frac{25.4\ \frac{\#}{\text{IN}^2} \times 144\ \frac{\text{IN}^2}{\text{FT}^2}}{.0290\ \frac{\#}{\text{FT}^3}}\right]^{-1/2} = .0201\ \text{FT}^2$$

$$\text{Area} = .0201\ \text{FT}^2 \times 144\ \frac{\text{IN}^2}{\text{FT}^2} = 2.90\ \text{IN}^2$$

$$h_2\ (\text{valve stroke}) = \frac{A_2}{\pi D} = \frac{2.90}{\pi\, 12.25} = \underline{.0755\ \text{IN}}$$

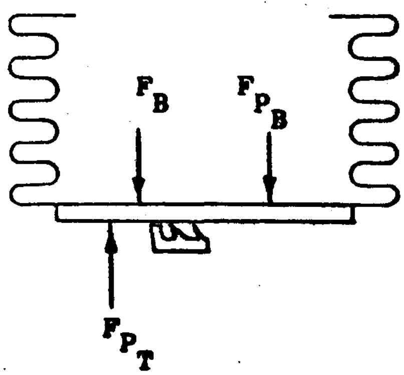
Flow Capacity (cont'd)

The stroke required for the BOV when operating as a 34.7 PSIG Relief Valve is only a portion of the total available stroke. Flow area @ max. lift = $\pi Dh = \pi 12.25(.6) = 23.1$ IN^2. Relief valve mode required flow area = 2.9 IN^2. Therefore, only $\frac{2.9}{23.1} = 12.5\%$ of valve flow area or stroke is required.

BOV Bellows Operating Pressures

The pressure required in the BOV Bellows Section @ cracking pressure of 33.5 PSIG is:

$$F_B + F_{P_B} = F_{P_T}$$



Where F_B = Force due to bellows preload

F_{P_B} = Force due to bellows internal pressure

F_{P_T} = Force due to pressure exerted on exposed seat area

$$300 + F_{P_B} = 33.5\ (77)$$

$$F_{P_B} = 2580 - 300 = 2280\#$$

$$\text{Bellows pressure} = \frac{F_{P_B}}{A_1} = \frac{2280\#}{86.5\ \text{IN}^2} = \underline{26.4}\ \text{PSIG}$$

The pressure required in the BOV Bellows Section @ full flow pressure of 34.7 PSIG with bellows compressed .0755 inches is:

$$F_{P_B} + F_B = F_{P_T}$$

$$F_B = 300\# + .0755\ (140\ \#/\text{IN}) = 310.6\#$$

$$F_{P_B} = 34.7\ (77) - 310.6 = 2360$$

$$\text{Bellows Pressure} = \frac{2360}{86.5} = \underline{27.3}\ \text{PSIG}$$

The above 27.3 PSIG pressure is based on uniform linear flow area increase with increasing bellows section stroke.

Oxidizer Tank Pressure Rise Rate

The oxidizer tank ullage pressure rise rate due to a failed open regulator prior to engine start is:

Tank ullage = 25 Ft^3

Tank liquid capacity = 2500 Ft^3 FLOX

$$W = \frac{PV}{RT} \qquad \dot{V} = \bar{V}\dot{P}$$

$$\dot{W} = \frac{P_o\dot{V}}{RT_o} + \frac{V_o\dot{P}}{KRT_o} \qquad \dot{V} = \frac{\bar{V}\dot{W}KRT_o}{V_o}$$

$$\dot{W} = \frac{P_o\dfrac{\bar{V}\dot{W}KRT_o}{V_o}}{RT_o} + \frac{V_o\dot{P}}{KRT_o}$$

$$\dot{W} - \left[\frac{P_o\bar{V}\dot{W}K}{V_o}\right] = \frac{V_o\dot{P}}{KRT_o}$$

$$\dot{P} = \left[\frac{\dot{W} - P_o\bar{V}\dot{W}K}{V_o}\right]\frac{KRT_o}{V_o} = \frac{\dot{W}KRT_o}{V_o}\left[1 - \frac{P_o\bar{V}\dot{W}K}{V_o}\right]$$

Where:

$\dot{P}$ = Press rise rate, PSI/SEC.

$\dot{W}$ = Flow rate, .75#/SEC.

$\bar{V}$ = Volume change per PSI, 267 IN^3/PSI.

P_o = Initial press, 44.7 PSIA.

V_o = Initial volume, 25 (1728) IN^3

T_o = Initial temp, 610°R.

R = Gas constant, 4630 IN-#/#/°R

K = Ratio specific heats, $1.66 = \frac{C_p}{C_v}$

$\dot{V}$ = Volume change rate, IN^3/Sec.

Oxidizer Tank Pressure Rise Rate (Cont'd)

$$\dot{P} = \frac{.75\ \frac{\#}{SEC}\ 1.66\ (4630\ \frac{IN}{°R})\ 610°R}{25(1728)\ IN^3} \quad X \quad \left[1 - \frac{44.7\ \frac{\#}{IN^2}\ 287\ \frac{IN^3}{PSI}\ 1.66}{25\ (1728)\ IN^3}\right]$$

$$= 81.5\ \left[1 - .458\right]$$

$$\dot{P} = 44.2\ PSI/SEC \quad = \quad \text{pressure rise rate}$$

The pressure rise rate will be less if the oxidizer tank regulator fails after engine start or if the pressure rise rate is due to FLOX boil-off from Aerodynamic heating.

Operating Response of the BOV Bellows Section

The relatively large (527 IN^3) volume of the GD/C BOV bellows section prevents the valve from responding immediately to signals from the control element. The total response time of the main BOV bellows section and controller is limited by the response time of main BOV bellows section. The maximum response capability of the BOV section is limited by the natural frequency of the bellows section.

The natural frequency, determined from the following equation is:

$$W_n^2 = \frac{2P_o A^2 K}{V_o M} + \frac{K}{M}$$

Where: W_n = natural frequency, RAD/SEC

P_o = pressure in bellows section 41.1, PSIA

A = area of bellows section seat, 86.5 IN^2

k = ratio specific heats, 1.66

V_o = volume of bellows section, 527 IN^3

M = mass of bellows section, $\frac{10\#}{386\ IN/SEC^2}$

K = bellows spring rate, 140#/IN

Operating Response of the BOV Bellows Section (Cont'd)

$$W_n^2 = \frac{2 \times 41.1 \frac{\#}{IN^2} \times (86.5)^2 \ IN^4 \times 1.66 \times 386 \ IN/SEC^2}{527 \ IN^3 \times 10\#} + \frac{140 \frac{\#}{IN} \times 386 \ IN/SEC^2}{10\#}$$

$$= 74{,}800 + 5400$$

$$W_n^2 = 80{,}200$$

$$W_n = 283 \ RAD/SEC$$

$$f_n = \frac{W_n}{2\pi} = \frac{283}{2\pi} = 45 \ cps$$

$$= \frac{1}{W_n} = .00353 \ SEC$$

The above value is the maximum response capability of the BOV bellows section with no damping. The response time of the damped control system is approximately ½ of the maximum, therefore,

$$f_{n_D} \approx 23 \ CPS$$

$$\tau_D \approx .007 \ SEC$$

The .007 SEC time constant expresses the time required for the bellows section to be at 63% of its full stroke with an infinite step input. Dead time is not included in this time constant. If tank pressure is at 31.0 PSIG and the airborne regulator fails open, the time elapsed from 33.0 PSIG to 34.7 PSIG is -

$$t = \frac{\Delta P \ Max}{\dot{P}} = \frac{34.7-33.0 \ PSI}{44.2 \ PSI/SEC} = \frac{1.7}{44.2} = .0385 \ SEC$$

This response time requirement is impractical for this type of a pneumatic control system.

Response time may be reduced if tank overpressurization is allowed. Burst pressure of the tank is approximately 43.0 PSIG when loaded with propellants prior to engine start. If the tank pressure is allowed to approach this max. burst pressure, the maximum time allowable for BOV response is:

$$t = \frac{\Delta P}{\dot{P}} = \frac{(43.0-33.0) \ PSI}{44.2 \ PSI/SEC} = .226 \ SEC$$

Operating Response of the BOV Bellows Section (Cont'd)

The controller must be able to respond to the pressure rise, and vent bellows section within .226 SEC. Assuming a dead time and a controller response time of approximately .10 SEC, the BOV bellows section pressure must be vented from 33.0 to 26.4 PSIG in .226-.1 = .126 SEC.

The pressure decay of the BOV bellows section will be rapid with the small volume and relatively large flow area. Therefore, the adiabatic venting process was selected for computation purposes. Nitrogen gas was assumed since the bellows section will contain various mixtures of GN_2, O_2, He and F_2.

The following computations are based on data from Ref. 3 for adiabatic venting of a constant volume into an infinite reservoir.

P_2 = downstream pressure = 19.7 PSIA (assumed 5 PSI back pressure)

P_i = initial bellows press = 47.7 PSIA

P_f = final bellows pressure = 41.1 PSIA

$$\frac{P_2}{P_i} = \frac{19.7}{47.7} = .413$$

$$\frac{P_2}{P_f} = \frac{19.7}{41.1} = .48$$

both values are in the inaccurate portion of the curve in Figure 5 Reference 3.

Therefore -

$$\mathcal{T}_f = \mathcal{T}\left[\frac{P_2}{P_f}\right] = \frac{2k}{k-1}\left[\frac{P_2}{P_f}\right]^{\frac{k-1}{2k}} = 7.0\left[\ .48\ \right]^{.143} = 6.3$$

$$\mathcal{T}_i = \mathcal{T}\left[\frac{P_2}{P_i}\right] = \frac{2k}{k-1}\left[\frac{P_2}{P_i}\right]^{\frac{k-1}{2k}} = 7.0\left[\ .413\ \right]^{.143} = 6.16$$

$$t = C\left[\mathcal{T}_f - \mathcal{T}_i\right]$$

$$C = \frac{t}{\mathcal{T}_f - \mathcal{T}_i} = \frac{.126}{6.30 - 6.16} = .90$$

$$C = \frac{}{C_i C_D A_T R k \sqrt{T_i}\left[\frac{P_2}{P_i}\right]^{\frac{k-1}{2k}}}$$

Operating Response of the BOV Bellows Section (Cont'd)

Where: C_1 = constant = $.523 \sqrt{\frac{°R}{SEC}}$ for nitrogen

C_D = discharge coefficient = .5 (assumed)

A_T = throat area, IN^2

R = gas constant, 662 IN-#/#/°R

k = ratio specific heats = 1.4

T_i = initial temp. 160°R (assumed)

V = volume of bellows, 527 IN^3

t = time = .126 seconds

$$A_t = \frac{V}{C\, C_1\, C_D\, Rk\, T_i \left[\frac{P_2}{P_1}\right]^{\frac{k-1}{2k}}}$$

$$A_t = \frac{527\ IN^3}{.523 \frac{\sqrt{°R}}{SEC}\quad .90 \quad .5 \quad 622 \frac{IN}{°R} \quad 1.40 \quad \sqrt{160°R} \quad \left[.413\right]^{\frac{1.4-1}{2.8}}}$$

$$A_t = \frac{527}{2280} = .231\ IN^2$$

$$d_t = \sqrt{\frac{4}{\pi} A_t} = .545\ IN$$

Therefore, a .545" vent port is required to vent the BOV bellow section from 47.7 PSIA (33.0 PSIG) to 41.1 PSIA (26.4 PSIG) in .126 seconds.

A .545" diameter poppet, actuated with tank pressure, would require a relatively large pneumatic actuator due to the high seating forces inherent with metal to metal seat configurations. It would be extremely difficult to design a control valve of this magnitude to meet the required response time, without using a separate external high pressure source and/or electrical actuation.

A series of blowdown tests conducted during the initial BOV development (GD/C Report #27B22-1 Ref. 4) were made from 27.0 PSIG tank pressures with various ullage volumes. The bellows motion traces, during the relief mode, shows that one side of the bellows section is forced wide open immediately upon unseating and oscillates while pivoting on the opposite side. This section of the bellows increases the effective opening area, forcing the valve to the full open position. This instability is expected since the bellows section is not guided axially and

Operating Response of the BOV Bellows Section (Cont'd)

depends upon a uniform spring rate about the circumference of the bellows section for uniform axial movement. This condition would also occur with the present BOV design during the proposed 33 PSIG vent mode.

When the BOV section is in the unstable condition, with the seal cocked full open on one side and pivoting on the opposite side, the time required to vent the 25 ft^3 ullage from 33.5 PSIG to 32.1 PSIG is as follows:

Flow area = ½ x π x seal diameter x stroke = ½ π x 12.25 x .6 = 11.5 IN^2

Following computations are based on data from Ref. 4 for adiabatic venting of helium:

P_2 = downstream pressure = 14.7 PSIA

P_i = initial tank pressure = 33.5 PSIG = 48.2 PSIA

P_f = final tank pressure = 32.1 PSIG = 46.8 PSIA

$$\frac{P_2}{P_i} = \frac{14.7}{48.2} = .306$$

$$\frac{P_2}{P_f} = \frac{14.7}{46.8} = .303$$

both values are in the inaccurate portion of the curve shown in Fig. 6. (Ref. 4).

Therefore,

$$\Upsilon_f = \frac{2k}{k-1}\left[\frac{P_2}{P_f}\right]^{\frac{k-1}{2k}} = \frac{2(1.66)}{1.66-1}\,(.308)^{\frac{1.66-1}{2(1.66)}} = 3.98$$

$$\Upsilon_i = \frac{2k}{k-1}\left[\frac{P_2}{P_i}\right]^{\frac{k-1}{2k}} = \frac{2(1.66)}{1.66-1}\,(.306)^{\frac{1.66-1}{2(1.60)}} = 3.97$$

$$c = \frac{V}{C_1\, C_D\, A_T\, Rk\, \sqrt{T_i}\,\left[\frac{P_2}{P_i}\right]^{\frac{k-1}{2k}}}$$

Operating Response of the BOV Bellows Section (Cont'd)

Where: $C_1 = .21 \dfrac{\sqrt{°R}}{SEC}$ for helium

$C_D = .5$ (Assumed)

$A_T = 11\ IN^2$

$R = 4630 \dfrac{IN\text{-}\#}{\#/°R}$

$k = 1.66$

$T_i = 150°F = 610°R$

$V = 25\ FT^3 = 25(1728)\ IN^3$

$$C = \frac{25(1728)}{.21 \quad .5 \quad 11 \quad 4630 \quad 1.66 \sqrt{610} \left[.306\right]^{.199}}$$

$$C = \frac{25(1728)}{173,000} = .25$$

$$t = C\left[\sqrt{T_f} - \sqrt{T_i}\right] = .25 \left[3.98 - 3.97\right] = \underline{.0025\ SEC}$$

The tank pressure will decrease from 33.5 to 32.1 PSIG if one side of the BOV seal is cocked open .60 IN for .0025 seconds. Since the valve is at this position for only about half this time for a given valve cycle, the above tank pressure decrease will take place in approximately .005 seconds. The design of a controller, with a separate external pressure supply and/or electrical solenoid actuation to obtain this reaction time, would incur added cost and weight penalities.

Allowing the oxidizer tank to drop below 32.1 PSIG into the flight pressure regulator band causes system instability between the regulator and relief valve. An extensive BOV redesign, in conjunction with above controller design, would be mandatory to eliminate the cocking before the valve could be used as an airborne relief valve.

SECTION II

FLOX-OXIDIZER TANK RELIEF VALVE DESIGN WITH ALL METAL COMPONENTS

OBJECTIVE

The objective of this investigation was to compare various pressure relief concepts with emphasis to be placed on the most promising devices. The following three design configurations were selected as the devices that would most satisfactorily meet the FLOX tank pressure relief requirements.

A. Relief Valve Incorporating an all Metal Lapped Spherical Seat.

B. Relief Valve Incorporating an all Metal Optical Flat Seat.

C. Relief Valve Incorporating a Rupture Disc Assembly.

CONCLUSIONS

1. The lapped spherical seat has the disadvantages of relatively large size, high unit weight, and slow response. The only possible advantage would be the ability to hand lap the mating seat surfaces in the installed condition, thereby, minimizing leakage.

2. The optical flat seat relief valve has the advantages of low unit weight, fast response and low seat leakage. However, the precision mating surfaces which must be maintained for low leakage are subject to a number of variables which may change the shape or condition of the seating surfaces.

3. The rupture disc-relief valve assembly has the advantages of relatively small size, low unit weight, extremely fast response, zero leakage, and low tolerance and relatively simple design. A possible disadvantage would be high leakage if a rupture occurred after lift-off. This would be due to the high leakage characteristics of the backup relief valve design.

PRESSURIZATION SYSTEM ANALYSIS

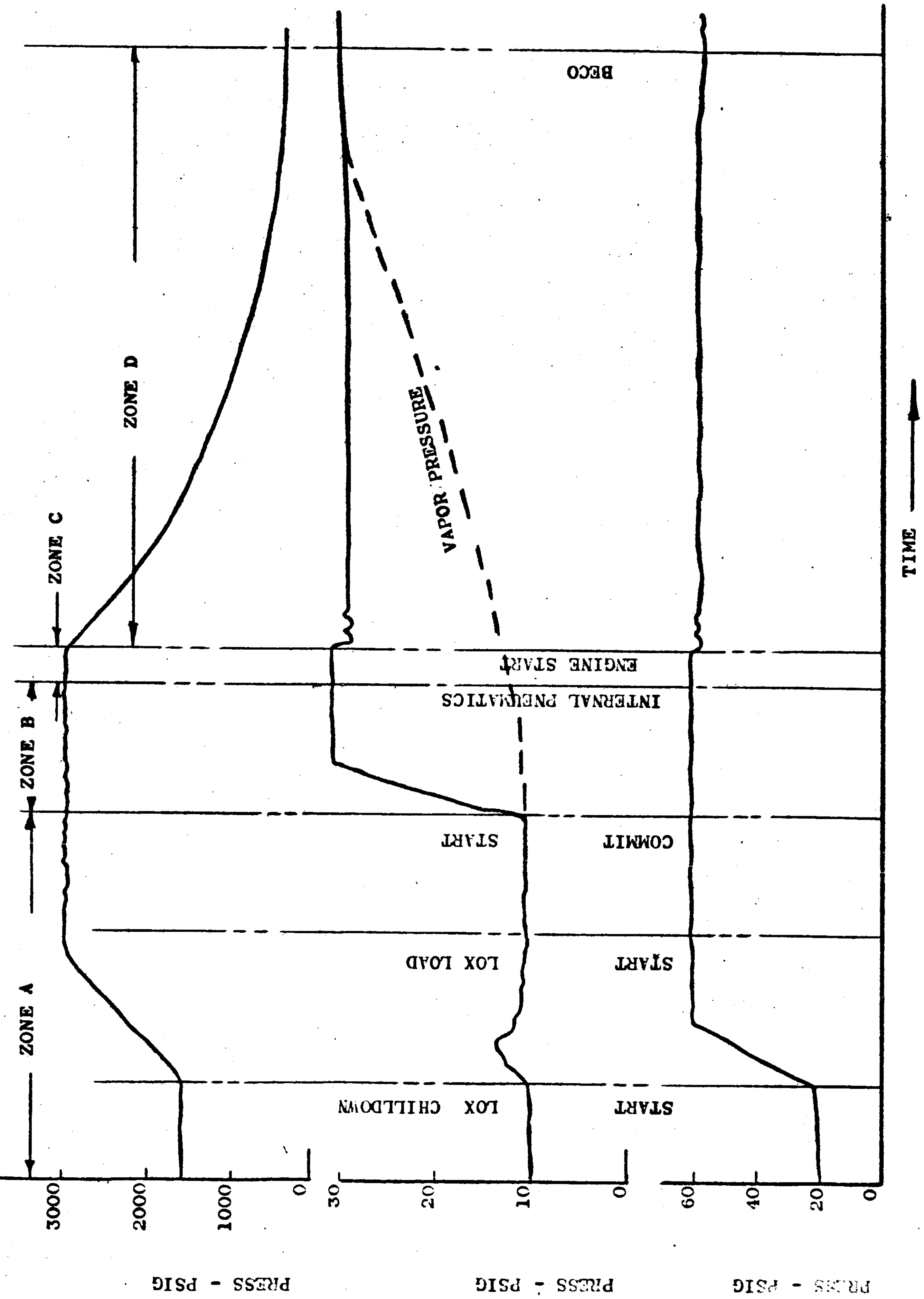
An analysis to determine what affect the three proposed relief valve configurations will have on various conditions requiring FLOX tank venting was based on the following assumptions:

1. Only single failures shall be considered.
2. Tank pressure is monitored continually.
3. Any pneumatic emergency aborts countdown.
4. The airborne regulator and relief valve will not have a common sense line.
5. FLOX boiloff is not a significant performance detriment after vapor pressure reaches relief valve cracking pressure.
6. Minimum burst pressure of the FLOX tank is at 38.7 psig ullage pressure.

The pressurization system failures considered, and their resulting effects are shown on Figures II and III.

PRESSURIZATION SYSTEM OPERATION

Fig II



PRESSURIZATION SYSTEM ANALYSIS

SYSTEM CONDITIONS	FIG II ZONE	SYSTEM RESULTS	
		PNEUMATIC ACTUATOR RELIEF VALVE	RUPTURE DISC-RELIEF VALVE ASSY
Failed closed boil off valve	A	No effect through countdown, abort and dual propellant loading (DPL)	No effect through countdown, abort and dual propellant loading (DPL)
PCU instrument air	A	No effect through countdown, abort and dual propellant loading (DPL)	No effect through countdown, abort and dual propellant loading (DPL)
Failed open A/B Regulator	C & D	Relief valve will vent intermittently, if engines are running, and will vent continuously, if prior to engine start.	Rupture disc will rupture - backup valve will vent continuously at the regulator flow rate.
Oxidizer vapor pressure rising to relief pressure	D	Relief valve will vent intermittently to maintain operating tank pressure	Rupture disc will rupture - backup valve will vent continuously at GOX vaporization rate
A/B regulator regulating 3-4 psi too high	D	Relief valve will vent intermittently to maintain operating tank pressure	No affect - rupture disc will not rupture

FIGURE III

PERFORMANCE REQUIREMENTS

The relief valve design must be capable of meeting the requirements of the -3 configuration shown in FLOX-Atlas Airborne Oxidizer Tank Relief Valve Performance Specification (Attachment 'A'). The basic requirements are:

1. Reseat pressure - 32.1 psig minimum.

2. Full flow pressure - 34.7 psig maximum.

3. Full flow rate - .80#/SEC of helium at 150°F @ 34.7 psig.

A. RELIEF VALVE INCORPORATING AN ALL METAL LAPPED SPHERICAL SEAT

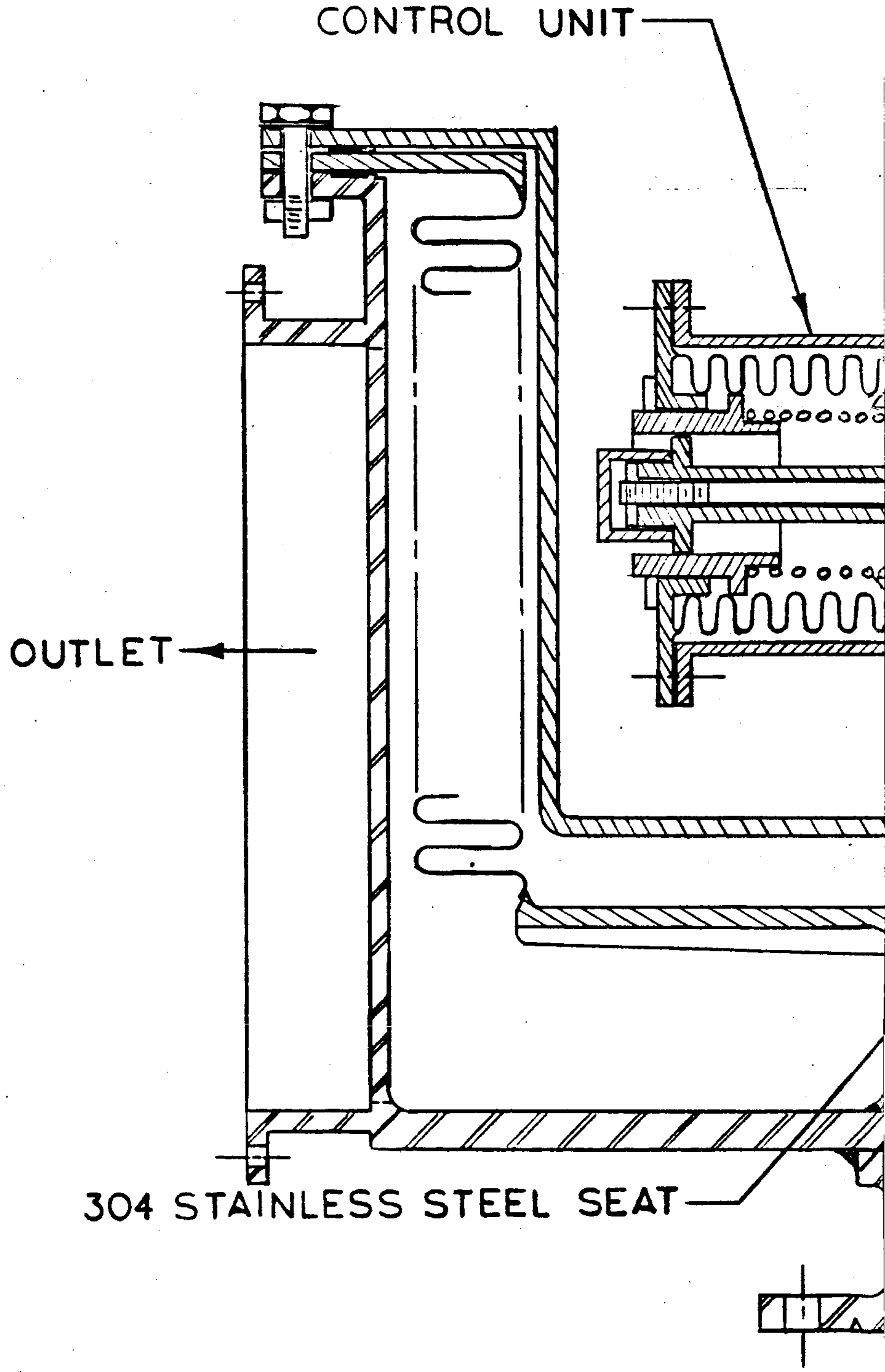
A pilot operating valve was selected because of the high seating forces required for minimum leakage with a metal to metal spherical seat configuration. The proposed valve configuration is shown in Figure IV.

DESCRIPTION OF OPERATION

The pilot valve consists of a pressure sensing bellows connected to the shaft of a 3-way valve. When the tank pressure is below the relief valve cracking pressure, the pilot valve vent port is closed and the supply port is open to tank pressure. The relief valve main bellows section is pressurized by the tank pressure thru the open supply port. The tank pressure within the main bellows acts across the differential seat area to hold the valve closed. As the tank pressure increases, the pilot valve bellows section is compressed, causing the valve shaft to open the vent port while simultaneously closing the supply port. The main relief valve bellows section is thus isolated from tank pressure and vented to atmosphere. The tank pressure can then compress the evacuated main relief valve bellows and lift the sealing ring from the seat. The relief valve will vent the tank pressure until the pilot valve pressure sensing bellows can expand sufficiently, under the decreasing tank pressure, to return the 3-way shaft to the closed position.

The pilot valve employs two spherical metal poppets -- a supply poppet and a vent poppet. The minimum leakage requirement applies only to the vent poppet since it is normally closed to maintain tank pressure on the main valve bellows. The supply poppet is normally open and is closed only during the relief mode. Since the main bellows is vented to atmosphere during the relief mode, supply poppet leakage is not critical except for the effect on valve response.

The pressurized bellows actuation concept was selected to obtain the minimum seat unit loading required for minimum leakage at 10 psig (standby) tank pressure.



LAPPED SPHERI

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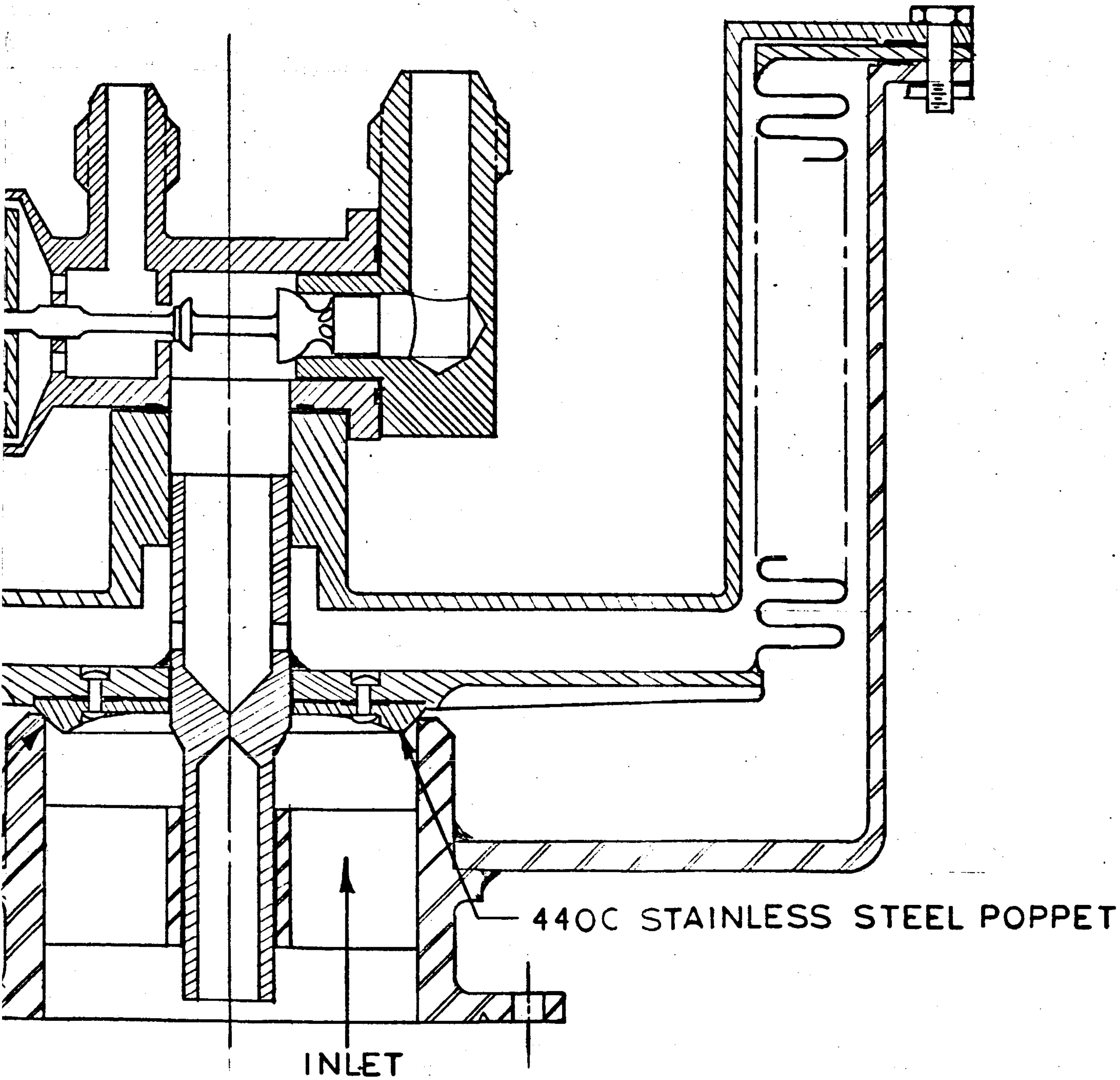


AL SEAT RELIEF VALVE

FIGURE IV

A. RELIEF VALVE INCORPORATING AN ALL METAL LAPPED SPHERICAL SEAT (continued)

DESIGN ANALYSIS

Poppet Design

The valve design calculations are based on a flow capacity 10% greater than the required helium flow rate of .80 #/sec (inlet gas pressure at 34.7 psig and 150°F). The required minimum flow area based on the orifice equation is:

$$\text{Area} = \frac{W}{C_s\, C_D\, \rho_1 \sqrt{2g\,\dfrac{(P_1 - P_c)}{\rho_1}}}$$

W = 1.10 x .80 = .88 #/sec -- flow rate

ρ_1 = .029 $\#/ft^3$ - density @ 49.4 PSIA @ 150°F

C_D = .50 (ASSUMED) - combined flow coefficient

g = 32.2 ft/sec^2 -- acceleration of gravity

P_1 = 49.4 PSIA - inlet pressure

P_c = $.486 x P_1$ - critical pressure

C_s = 1.058 - flow correction for super critical flow

$$\text{Area} = \frac{.88}{1.058 \times 0.50 \times 0.029 \times \sqrt{\dfrac{2 \times 32.2\ (49.4 - 24.0) \times 144}{.029}}}$$

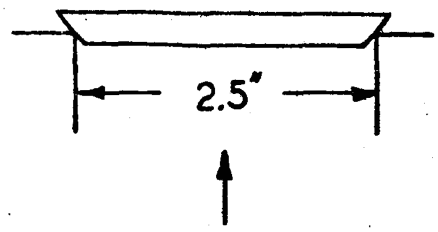
$$= .0201\ ft^2 = 2.90\ in^2$$

The minimum flow area diameter will be: $\text{DIA} = \sqrt{\dfrac{4.0 \times 2.90}{3.14}} = 1.93"$

A. RELIEF VALVE INCORPORATING AN ALL METAL LAPPED SPHERICAL SEAT (continued)

Poppet Design (cont'd)

Due to the high bellows spring rate in the spherical seat valve configuration, it was necessary to increase the poppet diameter to 2.50 inches. The diameter of the seat contact area is the same as the inlet chamber.



Bellows Design

Several undesirable airborne relief valve design requirements are inherent with large diameter metal to metal seat configurations. To provide a metal to metal seal with minimum leakage requires that the mating surfaces fit perfectly, or a force must be applied to yield one of the mating surfaces. It is extremely difficult to machine and maintain perfectly mating parts, and it is undesirable to yield the seat material, therefore, a compromise decision was made in order to determine the basis for the valve design.

The decision was made to design the valve for a 304 stainless steel seat with a minimum seat unit load equal to 10% of the seat material yield strength based on a .020 wide contact area. The valve was sized to meet the above conditions with 10 psig (standby) tank pressure.

Based on the above requirements, the minimum unit force (S_c) on the seat contact area is:

S_c = .10 x 30,000 psi (304 yield strength) = 3000 psi

The seat area (A_c) for a .020 inch wide line contact is:

$A_c = (3.14)(2.5)(.02) = .156 \text{ in}^2$

Therefore, the net force (F_N) required to hold the poppet closed is:

$F_N = (.156)(3000) = 468\#$

A. RELIEF VALVE INCORPORATING AN ALL METAL LAPPED SPHERICAL SEAT (continued)

Bellows Design (cont'd)

At 10 psig tank pressure the opening force on the poppet is:

$$F(\text{Tank Press}) = \frac{(3.14)\ (2.5)^2}{4}\ (10) = 49\#.$$

It is desirable to keep the bellows diameter as small as possible, therefore, numerous trial calculations were made to determine the optimum bellows preload to be utilized as part of the seating force. A preload of 50# was selected. The force that must be applied by bellows pressure is:

$$F(\text{Bellows Pressure}) = 468 + 49 - 50 = 467\#$$

The effective area and diameter of the bellows are:

$$A(\text{Bellows}) = \frac{467\#}{10\#/\text{in}^2} = 46.7\ \text{in}^2$$

$$DIA(\text{Bellows}) = \sqrt{\frac{4 \times 46.7}{3.14}} = 7.7''$$

The optimum design for a 321 stainless steel bellows with a 180,000 cycle life requires that the deflection ratio $\Delta/\Delta m = 0.38$ and the pressure ratio $P/Pm = 0.24$ where:

Δ = deflection per convolution per cycle

$$\Delta m = \text{maximum allowable deflection} = \frac{.0111\ a^3}{t^2\left[\frac{3xa}{t} + 1\right]}$$

P = operating pressure = 31.0 psig

$$Pm = \text{maximum allowable pressure} = \frac{3.7 \times 10^5\ t^2}{a\ (1.5 \times a + t)}$$

a = convolution depth

t = thickness of bellows material

Because of the large bellows diameter, these above optimum values resulted in a spring rate too high for this valve design. Increasing the pressure ratio (P/P_m) to .32 and decreasing the deflection ratio $(\Delta / \Delta m)$ to .26 resulted in the required spring rate and 180,000 cycle life.

A. RELIEF VALVE INCORPORATING AN ALL METAL LAPPED SPHERICAL SEAT (continued)

Bellows Design (cont'd)

To determine the above values, the equations were solved by trail and error. The final results were:

Bellows thickness (t) = .012"

Convolution depth (a) = .60 "

$$\Delta m = \frac{.0111\ (.60)^3}{(.012)^2 \left[\frac{3 \times .60}{.012} + 1\right]} = .11"$$

$$\Delta = \Delta m \times .260 = .11 \times .260 = .0286"$$

$$Pm = \frac{3.7 \times 10^5\ (.012)^2}{.6\ (1.5 \times .60 + .012)} = 98 \text{ psig}$$

For an effective flow area of 2.90 in^2 across the valve seat, the poppet must open:

$$h \text{ (Poppet Stroke)} = \frac{2.90}{(3.14\ (2.50)} = .370"$$

The number of convolutions (N) required is:

$$N = \frac{.370}{.0286} = 12.9 \text{ or } 13$$

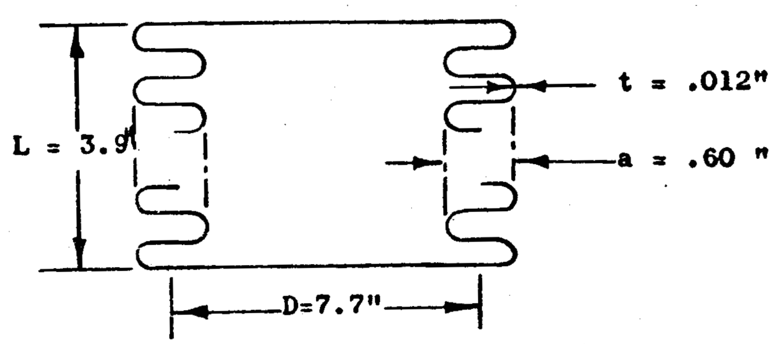
The approximate free length (L) is:

$$L = \frac{a}{2}\ N = \frac{.6}{2}\ (13) = 3.9$$

The spring rate (S.R.) is:

$$S.R. = \frac{(1.2)\ (3 \times 10^7)\ (7.7)}{13} \left(\frac{.012}{.6}\right)^3 = 170 \text{ \#/in}$$

The bellows dimensions are:



A. RELIEF VALVE INCORPORATING AN ALL METAL LAPPED SPHERICAL SEAT (continued)

Bellows Design (cont'd)

For a 50# preload, the bellows will be compressed (50/170) 0.294". The total deflection of the bellows in the full open position is (.294 + .370) = .664".

The force required to compress the bellows to full open position is (.664 x 170) = 113#.

The force available to compress the bellows to the full open position at 34.7 psig tank pressure is:

$$F(\text{Tank Pressure}) = \frac{(3.14)\ (2.5)^2}{4}\ (34.7) = 170\#$$

With tank pressure at 33.5 psig, the poppet will crack/reseat when the bellows chamber pressure (P_B) reaches:

$$P_B = \frac{(4.9)\ (33.5) - 50}{46.7} = 2.44 \text{ psig}$$

At operating tank pressure of 31.0 psig the unit stress (S_c) on the seat area is:

$$S_c = \frac{(46.7 - 4.9)\ \text{in}^2 \times 31.0 \text{ psi}}{.156\ \text{in}^2} = 8{,}620 \text{ psi}$$

Therefore, the unit stress = $\frac{8{,}620}{30{,}000}$ = 28.8% of the seat material yield strength. To minimize leakage, the design requires a precision lapped fit and a close tolerance alignment between the seat and poppet.

B. RELIEF VALVE INCORPORATING AN ALL METAL OPTICAL FLAT SEAT

A pilot operated valve was selected because of the high flow capacity-to-weight ratio coupled with a fast response. The proposed valve configuration is shown in Figure V.

Experimental tests conducted by Rocketdyne (References 1 and 2) indicate that optical flat seat leakage is primarily a function of the mating surface conditions. Per Reference (1), leakage tests were conducted on three .490 inch optical flat seat valve models made from three different materials -- 6061 aluminum alloy, 440C stainless steel and tungsten carbide. No attempt was made to interchange seat materials. The experimental tests supporting the theoretical predictions show that the super finished optical flat seat leakage for a given seat stress and surface condition was approximately the same for the three materials tested. Since super finish seats are vunerable to scratches and contamination, it can be concluded from these tests that a hard surface seat is most desirable.

Selection of the hard seat material was a compromise influenced by the operating environment and the ease of fabrication. The proposed valve incorporates a stellite seat and a 440C stainless steel poppet. A bead of stellite material would be deposited on the valve body seat area with a welding rod. The stellite would then be machined to an optical flat seat. The 440C stainless steel poppet would be machined separately and then fastened to the bellows assembly with rivets.

The following inherent problem areas associated with optical flat seats require further investigation:

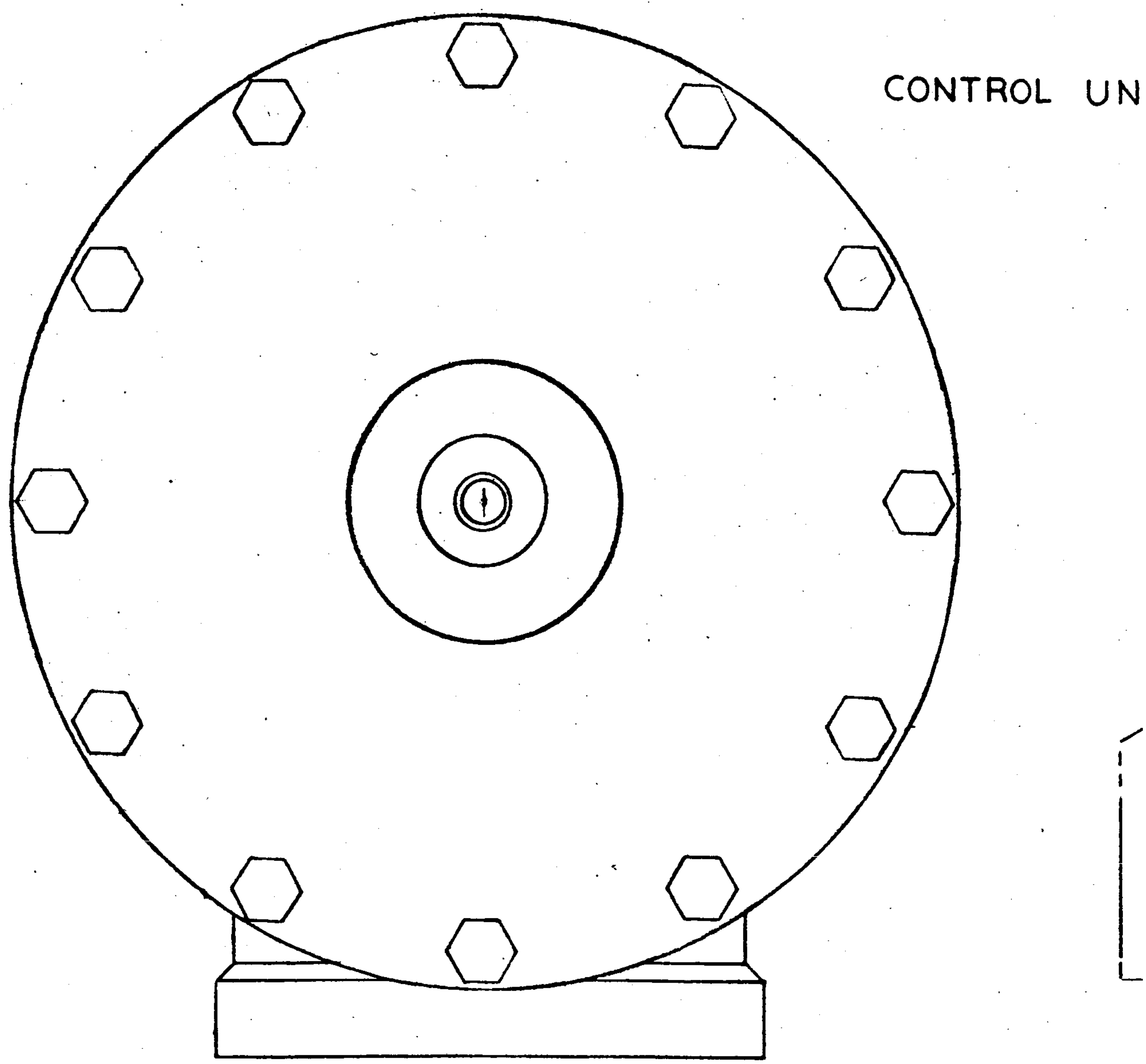
1. Distortion of seat and/or poppet due to thermal stresses and external forces.

2. Surface errosion.

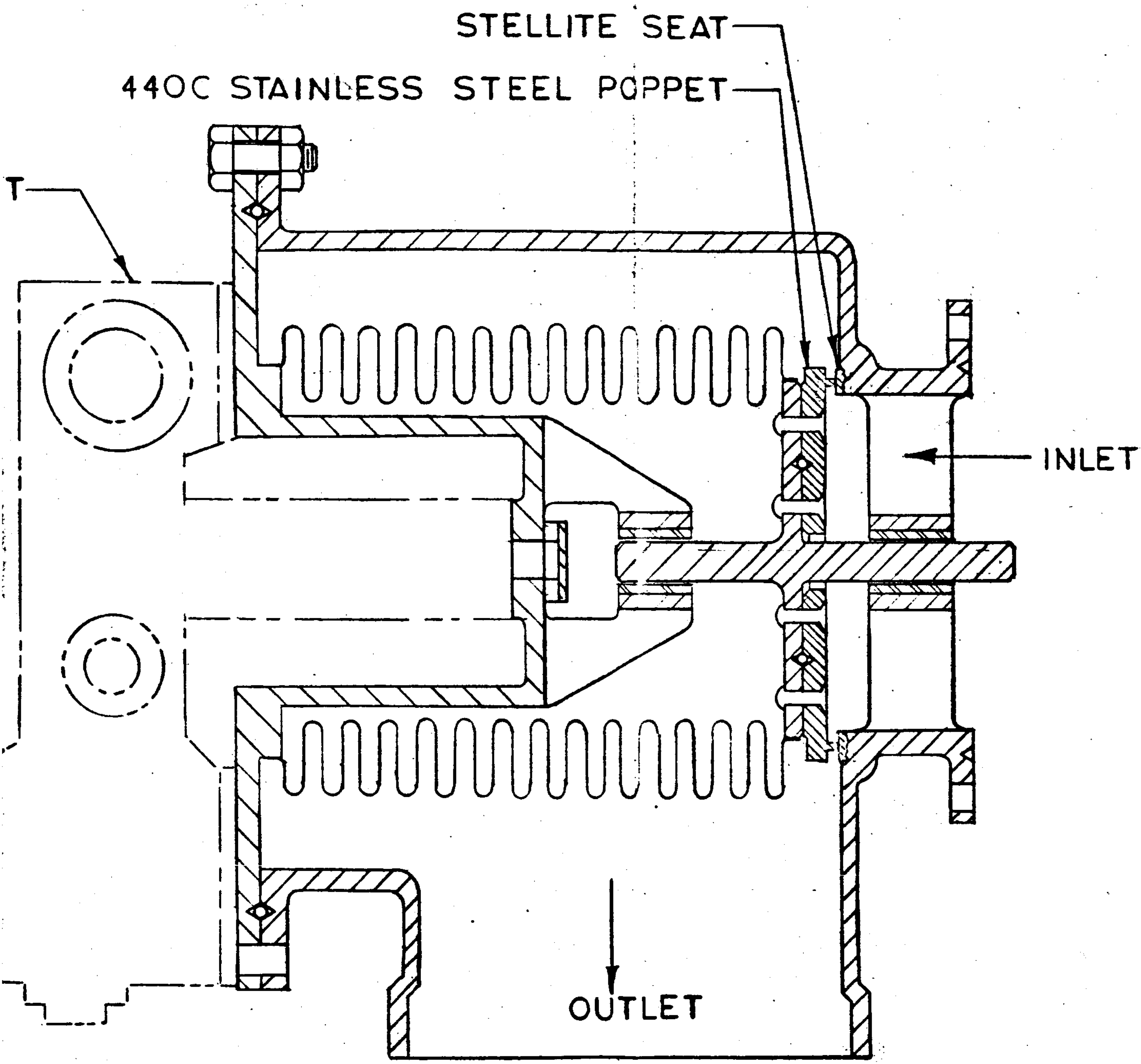
3. Contamination damage to superfinished surfaces.

4. Poppet to seat parallelism deviation caused by misalignment.

5. Quality control and measurement of an acceptable surface finish and flatness.



OPTICAL FLAT SE



AT RELIEF VALVE

FIGURE V

2

B. RELIEF VALVE INCORPORATING AN ALL METAL OPTICAL FLAT SEAT (continued)

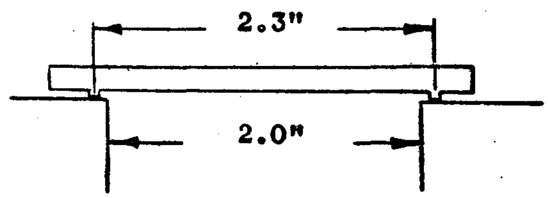
DESCRIPTION OF OPERATION

The pilot valve consists of a pressure sensing bellows connected to a three way valve. The pilot valve is similar in configuration and identical in operation to the pilot valve discussed under the spherical seat configuration.

DESIGN ANALYSIS

Poppet Design

As determined previously, under the spherical seat poppet design, the minimum valve inlet diameter is 1.93". It is desirable to keep the seat diameter as small as possible, therefore, a 2" diameter inlet and a 2.3" diameter seat contact was selected for the optical flat seat configuration.



Bellows Design

The effective area of the bellows is based on the assumed requirement that the force necessary to hold the poppet closed shall be a minimum of 25% greater than the opening force. At 10 psig tank pressure, the opening force on the poppet is:

$$F(\text{Tank Press}) = \frac{10.0 \times 3.14 \times (2.30)^2}{4} = 41.5\#$$

The minimum force required to hold the poppet closed will be:

$$F(\text{Bellows Press}) = 1.25 \times 41.5 = 52.0\#$$

Therefore, the effective bellows area and diameter is:

$$\text{Area (Bellows)} = \frac{52.0\#}{10.0 \text{ psi}} = 5.2 \text{ in}^2$$

$$\text{Dia (Bellows)} = \sqrt{\frac{4 \times 5.20}{3.14}} = 2.59"$$

B. RELIEF VALVE INCORPORATING AN ALL METAL OPTICAL FLAT SEAT (continued)

Bellows Design (cont'd)

The optimum design for a 321 stainless steel bellows with a 180,000 cycle life requires that the deflection ratio $\Delta/\Delta m$ = .038 and the pressure ratio P/Pm = 0.24 where:

Δ = deflection per convolution per cycle

$$\Delta m = \text{maximum allowable deflection} = \frac{.0111\ a^3}{t^2\left[\frac{3 \times a}{t} + 1\right]}$$

P = operating pressure = 31.0 psig

$$Pm = \text{maximum allowable pressure} = \frac{3.7 \times 10^5\ t^2}{a\ (1.5xa+t)}$$

a = convolution depth

t = thickness of bellows material

To determine the optimum values, the above equations were solved by trail and error. The final results are as follows:

Bellows thickness (t) = .014"

Convolution depth (a) = .60 "

$$\Delta m = \frac{.0111\ (.60)^3}{(.014)^2\left[\frac{3 \times .60}{.014} + 1\right]} = .090\text{"/convolution}$$

$$\Delta = .38 \times .090 = .0342\ \text{"/convolution}$$

$$Pm = \frac{3.7 \times 10^5\ (.014)^2}{.6\ \left[(1.5)\ (.60) + .014\right]} = 128\ \text{psig}$$

For an effective flow area of 2.90 in^2 across the valve seat the poppet must open:

$$h\ (\text{Poppet Stroke}) = \frac{2.90\ in^2}{(3.14)\ (2.30)\text{"}} = 0.40\text{"}$$

The number of convolutions (N) required is:

$$N = \frac{.40\text{"}}{.0342\text{"/convolution}} = 11.7 \text{ or } 12$$

B. RELIEF VALVE INCORPORATING AN ALL METAL OPTICAL FLAT SEAT (continued)

Bellows Design (cont'd)

The approximate free length of the bellows:

$$L \text{ (Bellows Free Length)} = \frac{a}{2} N = \frac{(.60)}{2} \times 12 = 3.6"$$

The spring rate of the bellows:

$$S.R. \text{ (Spring Rate)} = \frac{1.2\ E\ D}{N} \left(\frac{t}{a}\right)^3$$

E = Youngs mod = 3×10^7

D = effective bellows dia

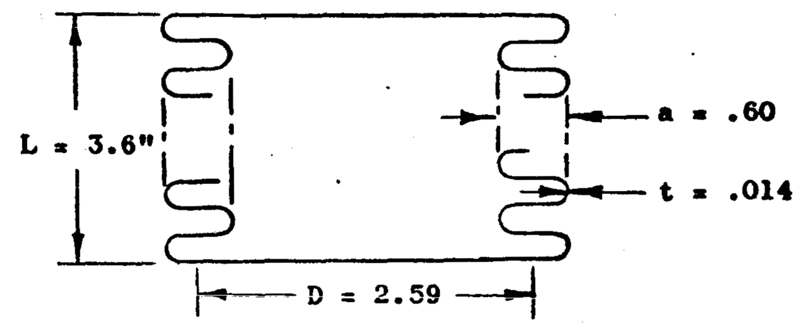
t = Bellows thickness

a = convolution depth

N = No. of convolutions

$$S.R. = \frac{(1.2)\ (3 \times 10^7)(2.59)}{12} \left[\frac{.014}{.60}\right]^3 = 100\ \#/\text{in}$$

The bellows dimensions are:



A 20# bellows preload was selected as a method of increasing valve stability under vibration, therefore, the bellows will be composed (20#/100#/in) 0.20" in the installed configuration. An additional force of (.40" x 100#/in) 40# is required to overcome the bellows spring rate in the full open position. With an inlet pressure of 33.5 psig, the poppet will crack/reseat when the bellows chamber pressure reaches $\frac{(4.15 \times 33.5 - 20.0)}{5.2} = 23$ psig.

C. RELIEF VALVE INCORPORATING A RUPTURE DISC ASSEMBLY

As a result of the preliminary relief valve design review, and succeeding customer direction (1432-RB-458), the decision was made to study a rupture disc assembly with a simple spring loaded back-up relief valve. This study was based on the assumption that the rupture disc assembly would be purchased from a qualified vendor, therefore, no effort was expended on the rupture disc design other than obtaining general information from rupture disc vendors and catalogues.

The rupture disc assembly would be installed on the forward FLOX tank bulkhead adjacent to the backup relief valve as shown in Figure VII. There would be approximately 3 feet of duct between the rupture disc and the FLOX tank relief port. Installing the relief assembly in this "dead-end" condition will expose the rupture disc to a gas mixture with a more uniform temperature.

DESCRIPTION OF OPERATION

The spring loaded relief valve is designed to crack/reseat at 32.1 psig and full flow at 34.7 psig. The rupture disc assembly would be designed to rupture at approximately 36.5 $\pm$ 1.5 psig as compared to the 34.7 psig full flow pressure stated in the design specification.

This higher rupture/relief pressure is required to prevent rupture from occurring due to normal pressurization pulses inherent in the airborne pneumatics system.

DESIGN ANALYSIS

Poppet Design

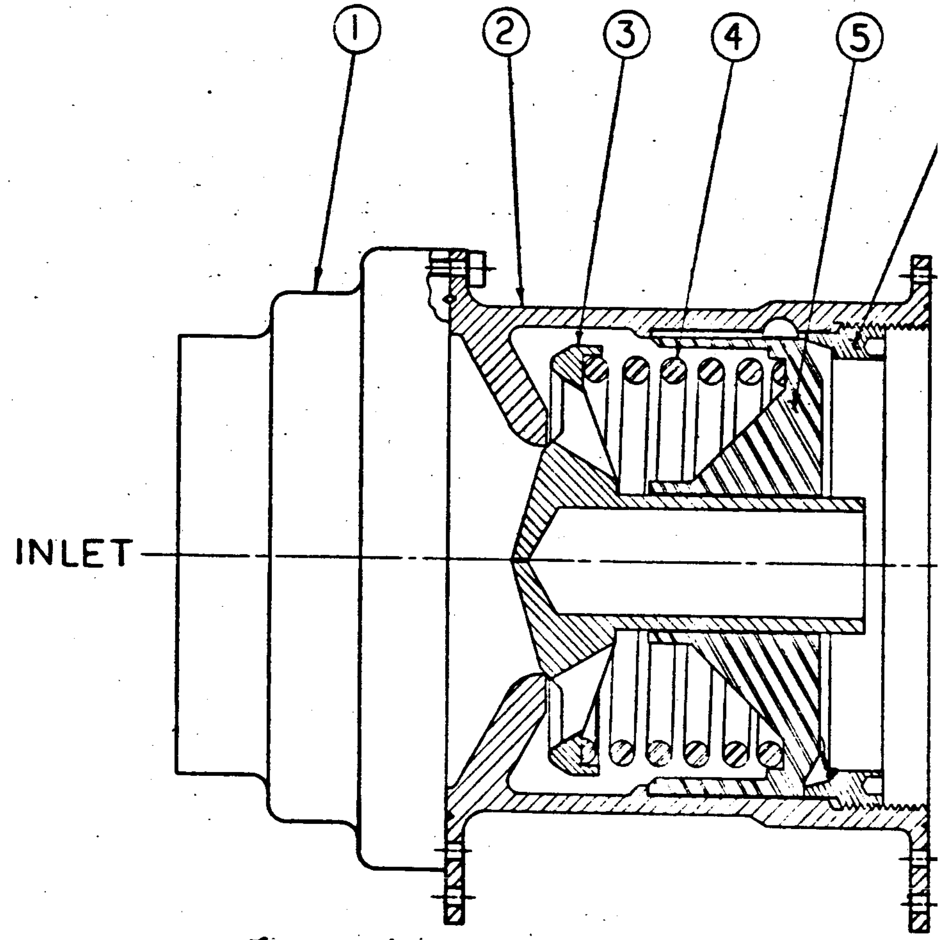
It was determined in the spherical seat design calculations that the minimum flow diameter and flow area, for the required .88#/sec (helium @ 34.7 psig and 150°F) flow rate, are 1.93" and 2.90 in^2, respectively. The optimum diameter for the backup relief valve poppet/seat contact area was determined to be 2.5" which is also the diameter of the valve inlet. For the required effective flow area of 2.90 in^2 the poppet must open.

h (Poppet Stroke) = 2.90/(3.14) (2.50) = 0.37"

Spring Design

At the crack/reseat pressure of 32.1 psig, the pressure force on the poppet is:

$$F = \frac{(3.14)\ (2.5)^2}{4}\ (32.1) = 157.5$$



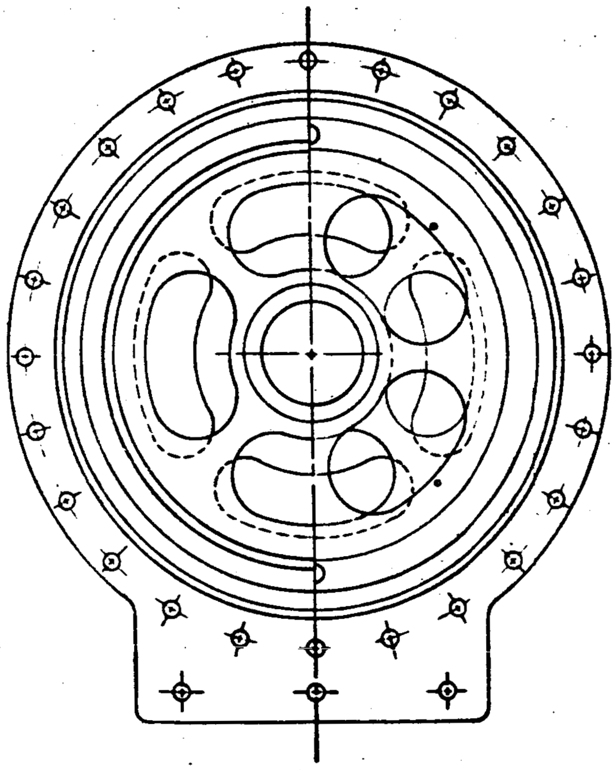
2.5" DIAMETER RUF

29-①

FIND NO.	DESCRIPTION	MATL
1	RUPTURE DISC ASSY	CRES
2	VALVE BODY	ALUMINUM ALLOY
3	POPPET	CRES
4	SPRING	INCONEL X
5	GUIDE	CRES
6	ADJUSTMENT NUT	CRES

6

—OUTLET



TURE DISC-RELIEF VALVE ASSY

FIGURE VI

C. RELIEF VALVE INCORPORATING A RUPTURE DISC ASSEMBLY (continued)

Spring Design (cont'd)

At the full flow pressure of 34.7 psig the pressure force on the poppet is:

$$F = 34.7 \frac{(3.14)\ (2.5)^2}{4} = 170.5 \text{ psig}$$

Therefore, the force available to open the poppet the required .37" is:

$$F = (170.5 - 157.5) = 13\#$$

As a result, the spring required to hold the poppet closed must have a spring rate (S.R.) of:

$$S.R. = \frac{13\#}{.37''} = 35\ \#/\text{in.}$$

In the installed configuration the spring must provide a force of 157.5#, therefore, the spring will be compressed:

$$\frac{157.5\#}{35\#/\text{in}} = 4.5''$$

After making several spring size calculations, the optimum mean spring diameter was selected as 4.2" and Inconel X was selected for the spring material.

Per GD/C Design Manual Figure 3-65, for average spring service of 100,000 cycles, the recommended maximum torsional stress for Inconel X material is 81,500 psi. As determined previously, the force that must be applied by the spring when the poppet is full open is 170.5#. Therefore, based on GD/C Design Manual Figure 3-15, for an axial load of 170.5#, mean diameter of 4.2", and a fiber stress in torsion of 75,000 psi, the required wire diameter is 0.283". Per GD/C Design Manual Figure 3-17, for the above conditions, the fiber stress correction for curvature is 1.085. This results in a corrected fiber stress in torsion of 81,500 psi which is equal to the recommended maximum value for Inconel X.

With the poppet full open, spring compressed to final length of 2.0", and a clearance between each coil equal to 10% of the wire diameter the total number of coils (TC) is:

$$TC = \frac{L}{1.1d} = \frac{2.0}{1.1 \times .283} = 6.43, \text{ USE } 6$$

The number of active coils (N) for a closed and ground end spring is:

$$N = TC - 2 = 6 - 2 = 4 \text{ coils}$$

C. RELIEF VALVE INCORPORATING A RUPTURE DISC ASSEMBLY (continued)

Spring Design (cont'd)

Based on the above values, the maximum stress (S_t) determined from the torsional stress equation is:

$$S_t = \frac{G\ d\ F}{\pi\ N\ D^2} \quad \text{where}$$

G = modulus of elasticity in torsion - 11×10^6 psi

d = diameter of wire ≑ .283"

F = deflection at full compressed length

= preload compressed length + stroke

= 4.50 + 0.37 = 4.87"

N = number of active coils - 4

D = mean coil diameter - 4.20"

$$S_t = \frac{11 \times 10^6 \times .283 \times 4.87}{3.14 \times 4 \times (4.2)^2} = 68{,}500 \text{ psi}$$

The curvature stress - correction factor (K) as determined from equation:

$$K = \frac{4C - 1}{4C - 4} + \frac{0.615}{C} \quad \text{where}$$

C = spring index = D/b = 4.2/.283 = 14.8

$$K = \frac{4 \times 14.8 - 1}{4 \times 14.8 - 4} + \frac{.615}{14.8} = 1.096$$

The maximum torsional stress is K x S_t = 1.096 x 68,500 = 75,000 psi

The final spring dimensions are:

FL = free length = 6.87"

IL = installed length = 2.37"

CL = compressed length = 2.00"

d = wire diameter = .283"

D = mean diameter = 4.20"

P = pitch = 1.575"

SR = spring rate = 35#/in

C. RELIEF VALVE INCORPORATING A RUPTURE DISC ASSEMBLY

RELIEF VALVE - RUPTURE DISC CONFIGURATION

The simple spring loaded relief valve configuration shown in Figure VI was designed using only five basic parts. The parts and their functions are:

1. Body: The valve body will be approximately 5.5" in diameter and 5.5" long and will be machined from an aluminum forging. Both valve ends will have identical flange configuration incorporating a metal "O" ring seal. The inlet flange will bolt directly to the rupture disc assembly and the outlet flange will bolt to the exhaust duct. The valve will be supported through mounting tabs on the inlet and outlet flanges. Also, the valve body will support the rupture disc assembly. The inlet duct will be bolted to the inlet of the rupture disc assembly and sealed with a metal "O" ring.

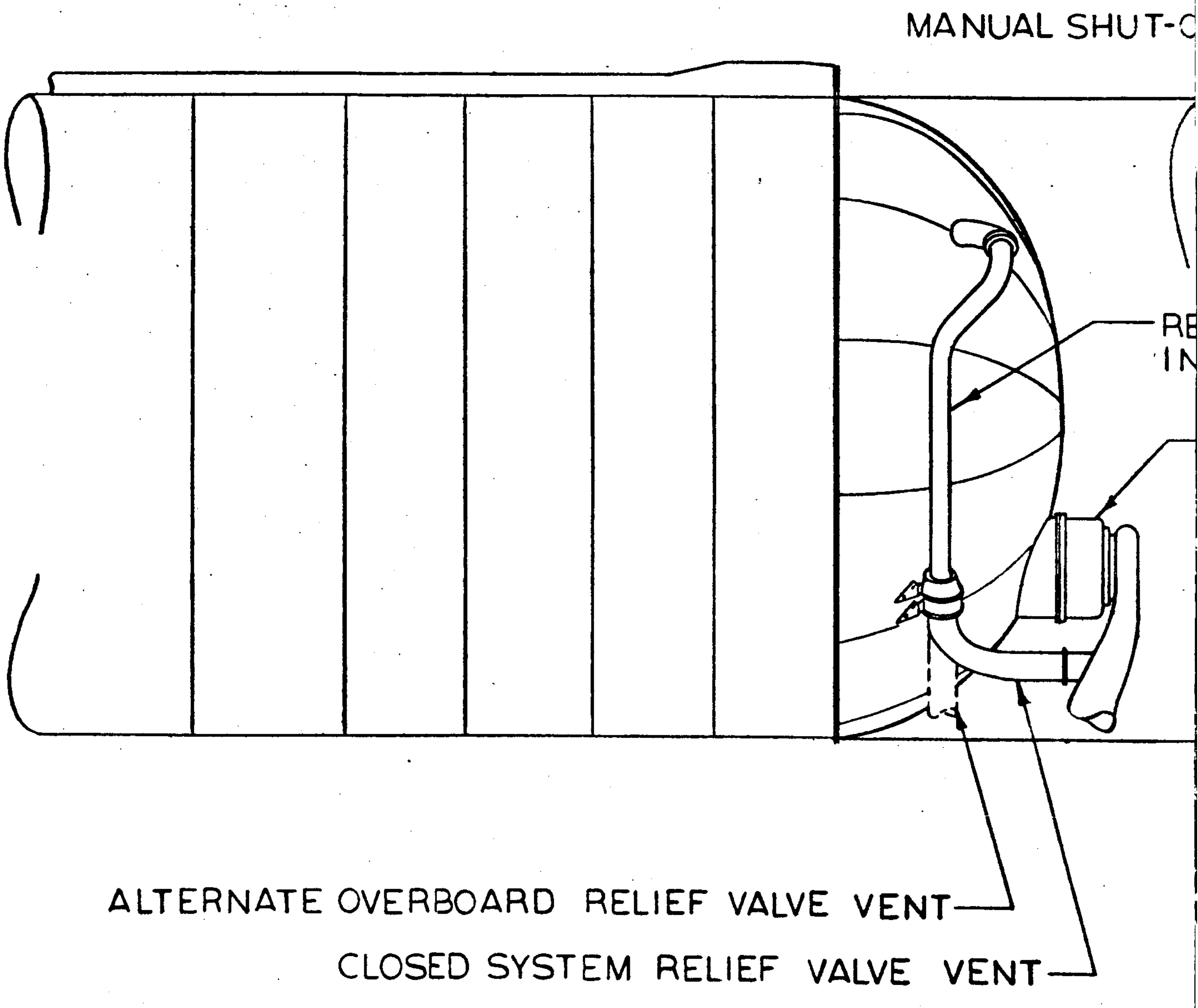
2. Poppet: The valve poppet will have a spherical seating surface and will be machined from 304 corrosion resistant steel. The poppet will have a .025" hole drilled through the center to provide a vent passage for the closed chamber between the rupture disc and relief valve poppet.

3. Poppet Guide: The poppet guide and integral spring retainer will be machined from 304 corrosion resistant steel. A keyway will be machined along the outside diameter of the guide to mate with a key in the valve body. This will prevent guide rotation and spring wind-up during adjustment and, also, provide a method for locking the adjustment nut.

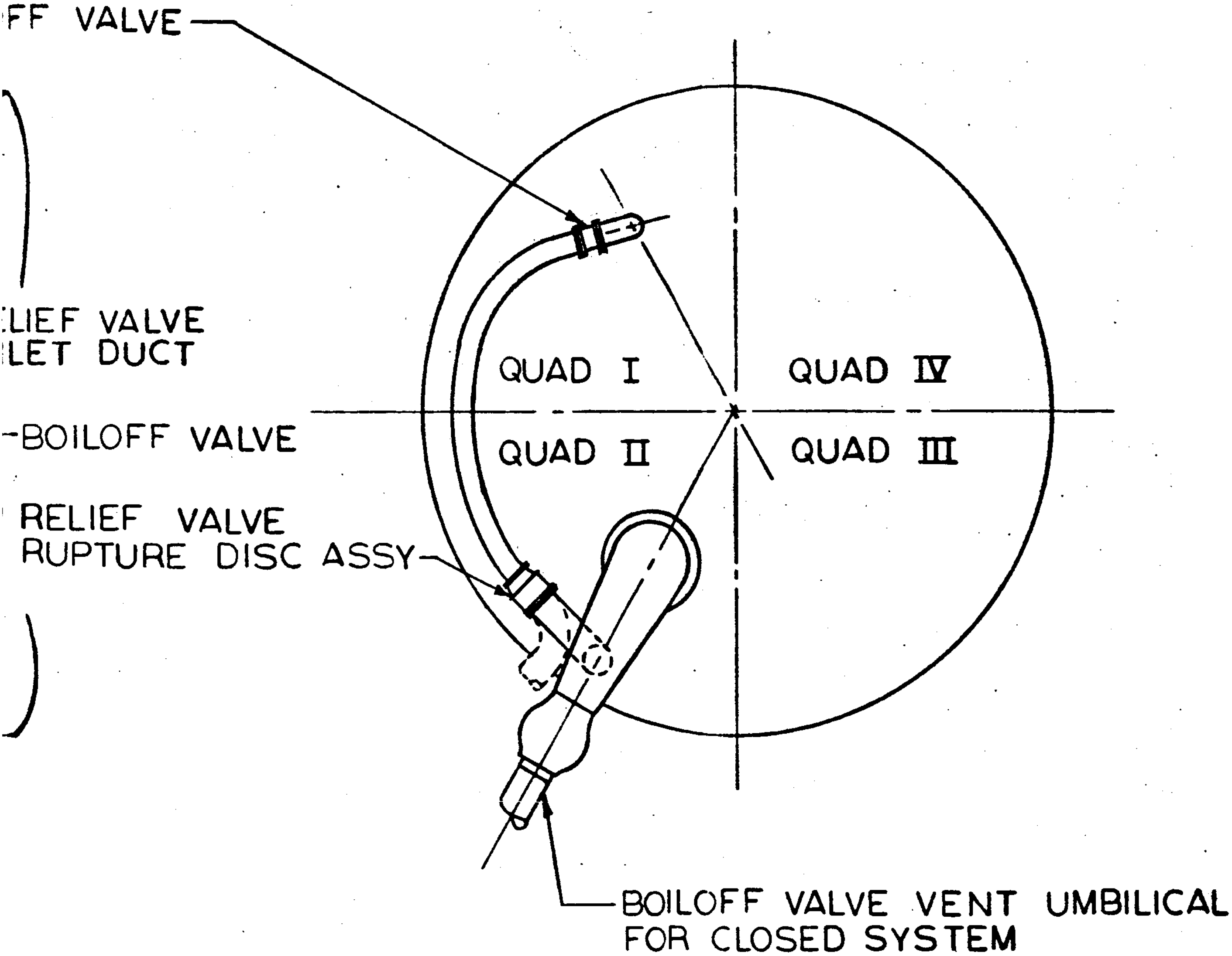
4. Adjustment Nut: The nut will be machined from 304 corrosion resistant steel. The nut would be used only for final adjustment after initial installation of the poppet-spring assembly.

5. Spring: The spring will be fabricated from Inconel X and heat treated to give the required spring rate.

The rupture disc assembly shown installed on the oxidizer tank in Figure VII, could be designed to meet the requirements of the performance specification. At present, rupture disc can be designed to operate at pressures to 95% of rupture setting. Disc rupture points can be pre-set with accuracies to 0.5%. Rupture disc assemblies are available with adjustable pressure setting, eliminating the need for precision manufacturing of burst disc. This type of assembly would be advantageous for use with FLOX due to the corrosive action that could take place on the rupture disc while exposed to a FLOX atmosphere.



RUPTURE DISC–RELIEF VALV



E INSTALLATION

FIGURE VII

C. RELIEF VALVE INCORPORATING A RUPTURE DISC ASSEMBLY (continued)

The main advantages of a rupture disc - relief valve assembly are:

1. Zero leakage under normal conditions.

2. Light weight compact design.

3. No threaded or moving parts exposed to FLOX under normal operating conditions.

4. Instantaneous venting if overpressurization occurs.

5. No requirements for lubrication.

6. Ease of cleaning.

The possible disadvantages of the rupute disc - relief valve assembly are:

1. The requirement to test several rupute disc from each production lot to verify the rupture pressure band.

2. High leakage rate through the backup relief valve if the rupture disc ruptures.

REFERENCES

1. Report #RPL-TDR-64-68, Rocket Engine Valve Poppet and Seat Design. Prepared by Rocketdyne - May 1964

2. Report #AFBMD-TR-60-74, Design Development and Testing of Advanced Helium Pressure Regulators, Part #551302. Contract AF04(647)-160, Prepared by Rocketdyne - July 1960

3. Report #AFBMD-TR-60-72, Analysis Design and Development of High Flow Helium Pressure Regulator. Contract No. AF04(647)-161. Prepared by Robertshaw-Fulton Controls - June 1960

4. Report #27B22-1, Development Testing of Convair Astro LO_2 Tank Relief and Shutoff Valve for "D" Series. Prepared by General Dynamics/Convair, March 1960

ATTACHMENT 'A'

PERFORMANCE SPECIFICATION

OXIDIZER TANK RELIEF VALVE

FLOX-ATLAS, AIRBORNE

25 June 1965

Contract Number NAS3-3245
TCP 8459 NASA/LeRC

Task Order #5

Prepared by C. W. Aulgur
C. W. Aulgur
Pneumatics Design
A.M.C.

Approved by H. E. Wright
H. E. Wright
Assistant Chief Engineer
Fluid Subsystems

Approved by W. A. Roberts
W. A. Roberts
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Approved by
M. E. Stone
Chief, Systems Requirements

REVISIONS

No.	Date	By	Change	Page
A	22 July 1965	D. L. Gray D. L. Gray	Delete TFE Spray	4
		A.M.C.	Add 2.1.1.6	4
		[illegible]	Add 2.1.2.8	5
		W. Roberts	-300° was -290°	6
			-300° was -290°	7

ABSTRACT

This document describes the performance specifications for two different configurations of a vehicle-borne FLOX-ATLAS oxidizer tank pressure relief valve to be located on top of the Atlas oxidizer tank within the Atlas/Centaur clearance envelope.

Each relief valve shall be designed to prevent the oxidizer tank pressure from increasing above the pressure specified in the design requirements. The valves shall be designed to function automatically.

The two different configurations shall be identified as:

XXXX-1
XXXX-3

PERFORMANCE SPECIFICATION
OXIDIZER TANK PRESSURE RELIEF VALVE
FOR A FLOX-ATLAS VEHICLE

1.0 INTRODUCTION

1.1 Scope

This document specifies the design criteria for the FLOX oxidizer tank pressure relief valves and establishes the basic capability of the component to perform the necessary functions. It shall serve as the internal control for design in order to maintain compatibility with requirements of the pneumatic system.

1.2 Applicable Documents

A. Military Specifications

MIL-E-5272A 16 September 1952	Environmental Testing, Aeronautical and Associated Equipment
MIL-P-27401B 19 September 1962	Propellant-Nitrogen Pressurizing
U.S. Bureau of Mines Grade-A	Helium Gas
MIL-C-5015D 17 December 1958	Connectors, Electrical "AN" Type
MIL-B-5087A(1) (AGS)	Bonding; Electrical (for Aircraft)
MIL-I-6865D(1) 27 October 1959	Inspection, Radiographic
MIL-S-7742(1) 28 May 1956	Screw Threads, Standard Aeronautical
MIL-R-11468 27 September 1951	Radiographic Inspection, Soundness Requirements for Arc and Gas Welds in Steel

B. Publications

Air Force-Navy-Aeronautical Bulletins

143d 19 August 1954	Specifications and Standards, Use of

Contractor

0-75002	Cleaning Procedures - Liquid Oxygen System Components
0-75019	Packaging of Missile System Components
0-75063	Specification for Unfilled Polytetrafluorethylene (Teflon)
7-00209B 1 March 1958	Environmental Design Conditions and Environmental Test Procedures for WS-107A-1 Equipments, Specification for
69-00202B 21 January 1964	Environmental Design and Test Criteria Specification for Space Launch Vehicles Vehicleborne and Aerospace Ground Equipment

2.0 REQUIREMENTS

2.1 Design Requirements - General

2.1.1 Materials. Materials in contact with FLOX vapor or liquid shall be compatible with liquid or gaseous oxygen and liquid and gaseous fluorine in any mixture ratio.

2.1.1.1 Metals. Only metallic bellows or diaphragms and metallic static seals shall be specified, except as noted in paragraph 2.1.1.10.

2.1.1.2 Lubrication. The relief valves shall be designed to function properly without lubrication of any parts and/or assembly.

2.1.1.3 Screw Threads. Threaded detail parts shall be specified only as required to substantially simplify the design.

2.1.1.4 Decontamination Requirements. Prime consideration in design shall be given to providing for ease of cleaning, purging, inspection, and contamination control.

2.1.1.5 FLOX Entrapment. Prime consideration shall be given to minimizing FLOX entrapment within the relief valves, for personnel safety purposes during disassembly, after being exposed to a fluorine environment.

2.1.1.6 Passivation. Prime consideration shall be given to provide for ease of passivation, by allowing flow to all cavities which require exposure.

2.1.1.7 Environmental Requirements. The design shall conform to environmental requirements per GD/C Report 69-00202B, 21 January 1964.

2.1.1.8 Joining. The design shall provide for welding in preference to brazing; however, brazing is not prohibited.

2.1.1.9 Limitations. The following materials shall not be used in the design:

2.1.1.9 (Continued)

a. Carbon and rubber
b. Cadmium plating
c. Titanium

2.1.1.10 Teflon. The main poppet seal of the -1 configuration shall be the only seal made of Teflon.

2.1.2 Electrical Requirements for -1 Configuration

2.1.2.1 Electrical Bonding. Electrical bonding shall be provided in accordance with specification MIL-B-5087.

2.1.2.2 Receptacles and External Connections. Receptacles shall be in accordance with specification MIL-C-5015, except that contacts shall be gold plated to a minimum thickness of .0001 inches.

2.1.2.3 Dielectric Strength. Electrical components shall be capable of withstanding 100 volts, rms, 60 cycles, between each lead and all other leads when grounded to the case and are not internally connected to the test lead.

2.1.2.4 Insulation Resistance. The insulation resistance shall be not less than 200 megohms when measured between each lead and all other leads when they are grounded to the case and are not internally connected to the test lead.

2.1.2.5 Grounding. The design and construction of the relief valve shall be such that all external parts shall be at ground potential.

2.1.2.6 Electrical Schematic. The electrical control circuit shall be per Figure I.

2.1.2.7 Voltage. The solenoid shall be designed to operate intermittently with a maximum current requirement of 3.0 amps at 29 volts (DC) at a temperature of +78° F. Minimum voltage requirement shall be 24 volts (DC). Maximum operating temperature shall not exceed 100° F.

2.1.2.8 Sealing. The electrical system shall be isolated from the fluid medium in all respects.

2.1.3 Working Fluid

2.1.3.1 Non-operating. The relief valve shall be designed to function within the requirements of this document after being exposed to the following fluid media:

a. Liquid oxygen and liquid fluorine in any mixture ratio.

b. Gaseous oxygen and gaseous fluorine in any mixture ratio.

c. Dry gaseous nitrogen - the AGE oxidizer tank pressurization fluid media during transportation, standby on launcher, and countdown.

2.1.3.2 Operating. The relief valve shall be designed to operate against a pressure fluid media of liquid oxygen and liquid fluorine, gaseous oxygen and gaseous fluorine, and gaseous helium and gaseous nitrogen combined in any ratio. The temperature of the media shall range from -300° F to $+450^{\circ}$ F.

2.1.4 Vibration Requirements

The relief valves shall be designed to conform to the Atlas/Centaur adapter area (airframe mounted equipment) simultaneously combined sinusoidal/random vibration, as shown in Figures II, III, and IV.

2.1.5 Storage and Transportation Environments

The relief valves shall be capable of safe storage and transportation without impairment of capabilities from the effects of non-operating environments, as specified in GD/A Report 7-00209B and paragraph 2.1.3.1.

2.1.6 Weight and Size

The weight and size of the relief valves shall be held to a minimum consistent with good design practices. The maximum weight guideline shall be:

a) -1 Configuration - 50 pounds
b) -3 Configuration - 5 pounds

2.2 Design Requirements - Detail

2.2.1 Requirements for -1 Configuration

2.2.1.1 Configuration. The -1 shall be similar to the existing GD/C valve, Part No. 55-80209. Modifications to the relief valve shall be made to meet the requirements of this specification. The configuration is schematically illustrated by Figure V.

2.2.1.2 Operation. The design of the -1 shall be such that it will function during three modes:

Mode 1: Propellant Loading
While solenoid selected to Mode 1, with inlet pressure increasing at a maximum rate of 1.0 psig/sec., the valve shall flow a minimum of 15 lbs/sec. (gaseous FLOX at -300° F) at an inlet pressure of 12.0 psig. With inlet pressure decreasing at a maximum rate of 1.0 psig/sec., the valve shall close (reseat) at a minimum inlet pressure of 9.5 psig.

Mode 2: Internal Pneumatics - Shut-off
While solenoid selected to Mode 2, the valve shall act as a shut-off valve against inlet pressures ranging from 0 psig to a maximum of 34.7 psig.

Mode 3: Internal Pneumatics - Relieving
Operating automatically in Mode 3, with inlet pressure increasing at a maximum rate of 1.0 psig/sec., the valve shall flow a minimum of 0.80 lb/sec. (gaseous helium at 150° F) at an inlet pressure of 34.7 psig. With inlet pressure decreasing at a maximum rate of 1.0 psig/sec., the valve shall close (reseat) at a minimum inlet pressure of 32.1 psig. The valve shall not inadvertently relieve (crack) if inlet pressure is varied from 0 psig to 28 psig at a maximum rate of 10.0 psig/sec.

2.2.1.3 Proof Pressure. No component of the relief valve shall fail when subjected to 42.0 psig.

2.2.1.4 Burst Pressure. No component part of the relief valve shall rupture when subjected to 52.0 psig.

2.2.1.5 Leakage. The allowable leakage for the -1 configuration, inlet pressurized with 31 psig helium gas at $+70^{\circ}$ F and subjected to vibration per paragraph 2.1.4, shall not exceed:

a) 2 scfm internal leakage through main valve and controllers.

b) 5scc/hr external leakage.

2.2.2 Requirements for -3 Configuration

2.2.2.1 Configuration. The -3 configuration shall be composed of two major components:

a) Signal pressure sensing and controller
b) "Main" Valve and body assembly

2.2.2.2 Operation. The -3 configuration shall be such that, operating automatically with inlet pressure increasing at a maximum rate of 1.0 psig/sec., the valve shall flow a minimum of .80 lb/sec. (gaseous helium at 150° F) at an inlet pressure of 34.7 psig. With inlet pressure decreasing at a maximum rate of 1.0 psig/sec., the valve shall close (reseat) at a minimum inlet pressure of 32.1 psig. The valve shall not inadvertently relieve (crack) if inlet pressure is varied from 0 psig to 28.0 psig at a minimum rate of 10.0 psig/sec.

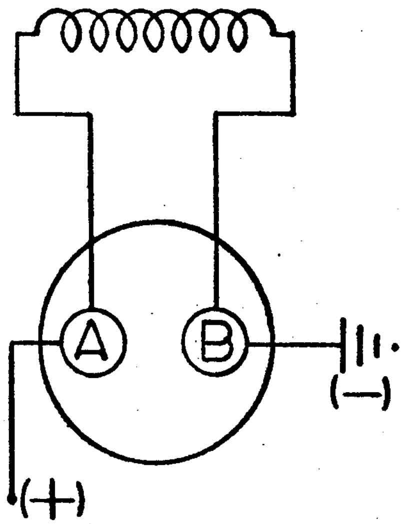
2.2.2.3 Proof Pressure. No component of the relief valve shall fail when subjected to 53.0 psig.

2.2.2.4 Burst pressure. No component of the relief valve shall rupture when subjected to 70.0 psig.

2.2.2.5 Leakage. The allowable leakage for the -3 configuration, inlet pressurized with 31 psig helium gas at $+70^{\circ}$ F, and subjected to vibration per paragraph 2.1.4, shall not exceed:

a) 138 scim internal leakage through main valve
b) 125 scim internal leakage through controller
c) 5scc/hr external leakage

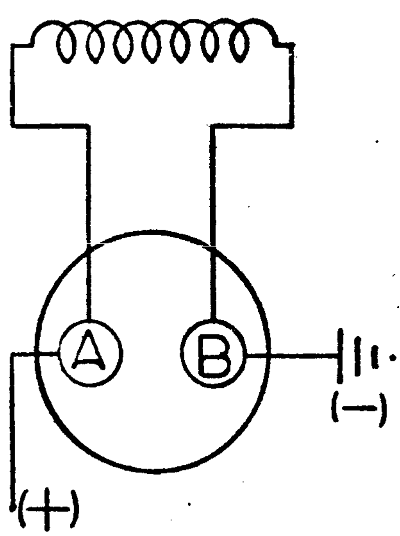
ELECTRICAL SCHEMATIC FOR -1 CONFIGURATION



LOCKING SOLENOID

Mode 1: "A" (+) Energized

Mode 2 and 3: "A" (+) De-energized



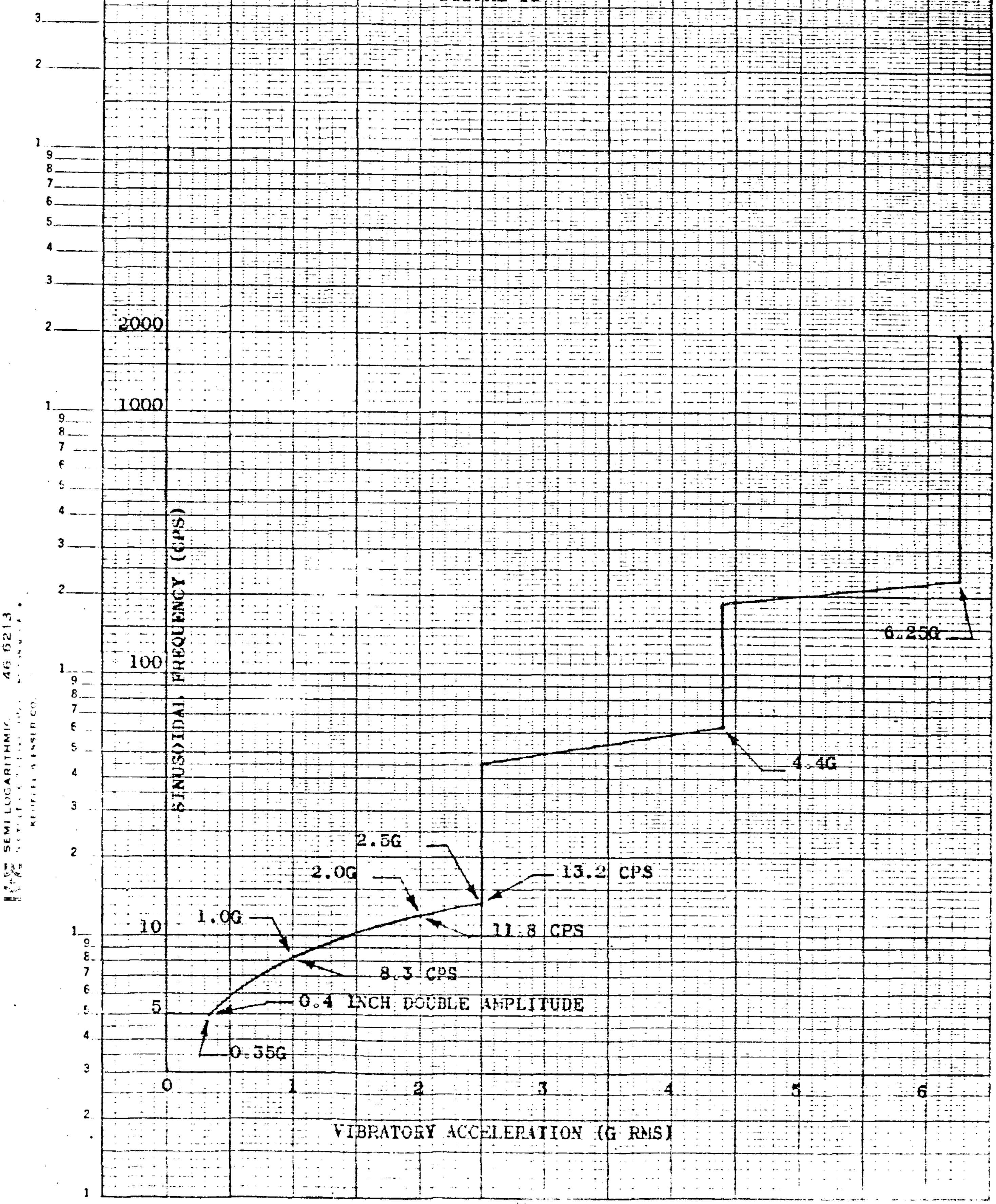
ACTUATING SOLENOID

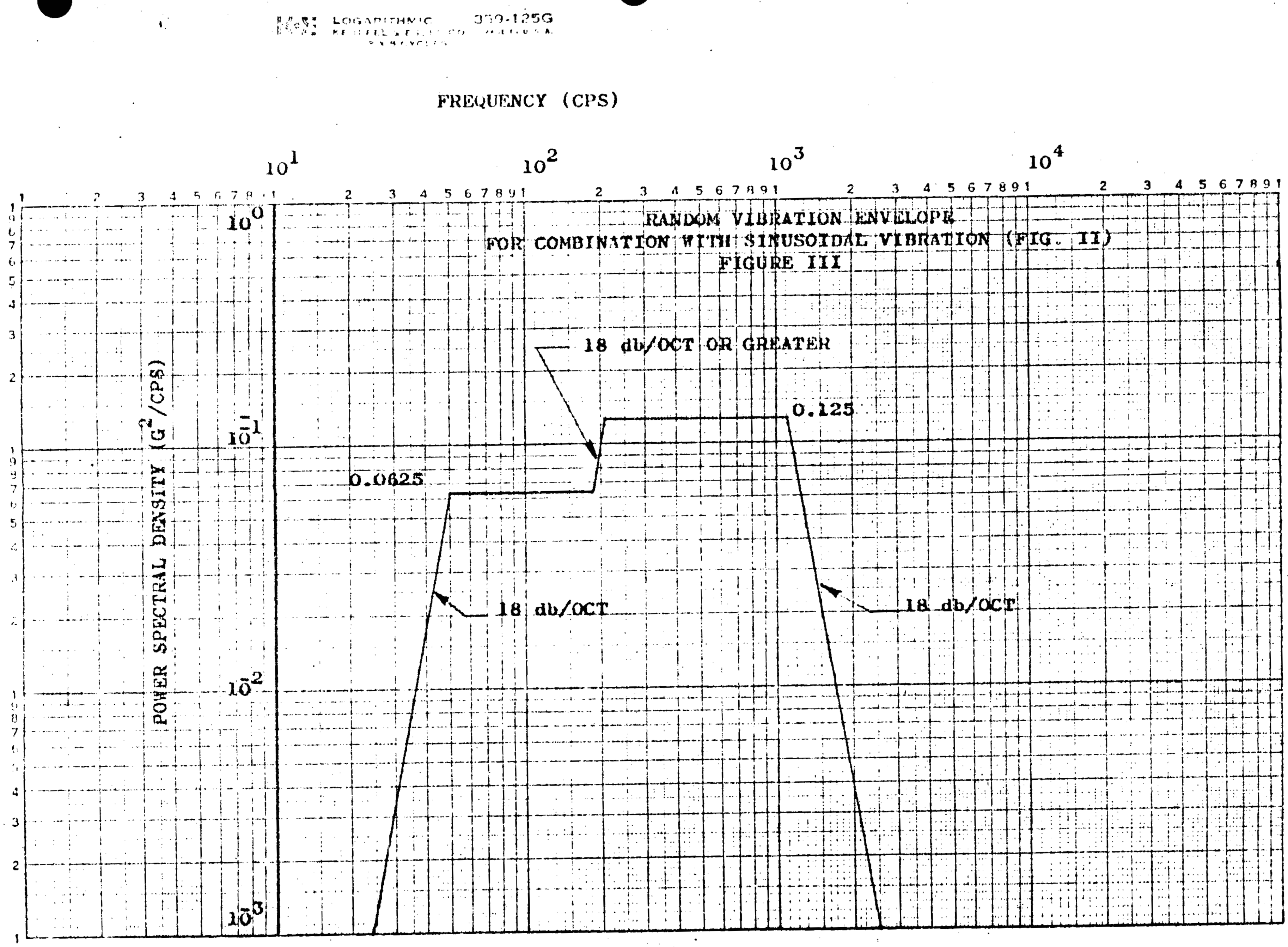
Mode 1: "A" (+) De-energized

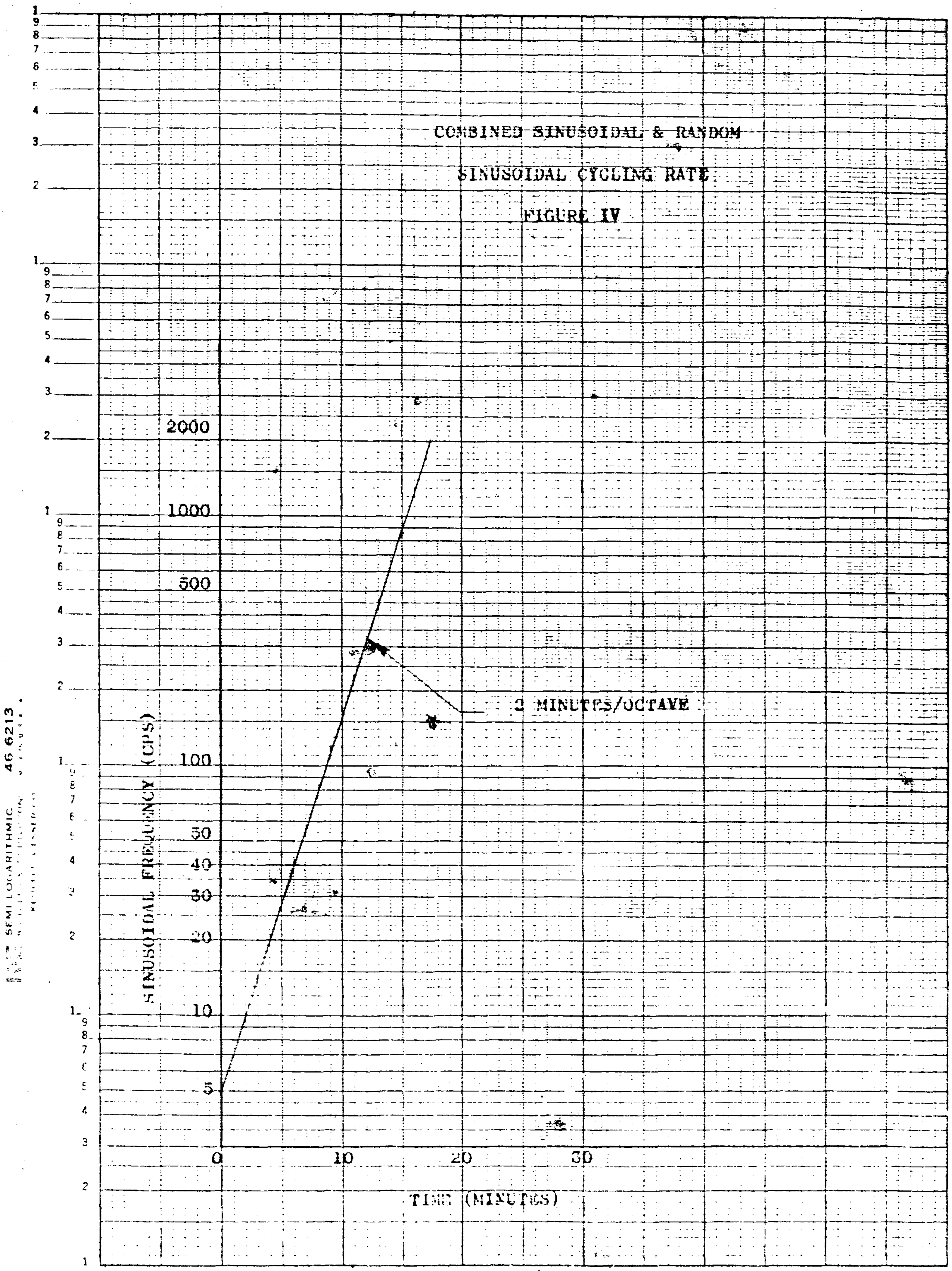
Mode 2 and 3: "A" (+) Energized

FIGURE I

SINUSOIDAL VIBRATION LEVEL
FOR COMBINATION WITH RANDOM VIBRATION (FIG. III)
FIGURE II

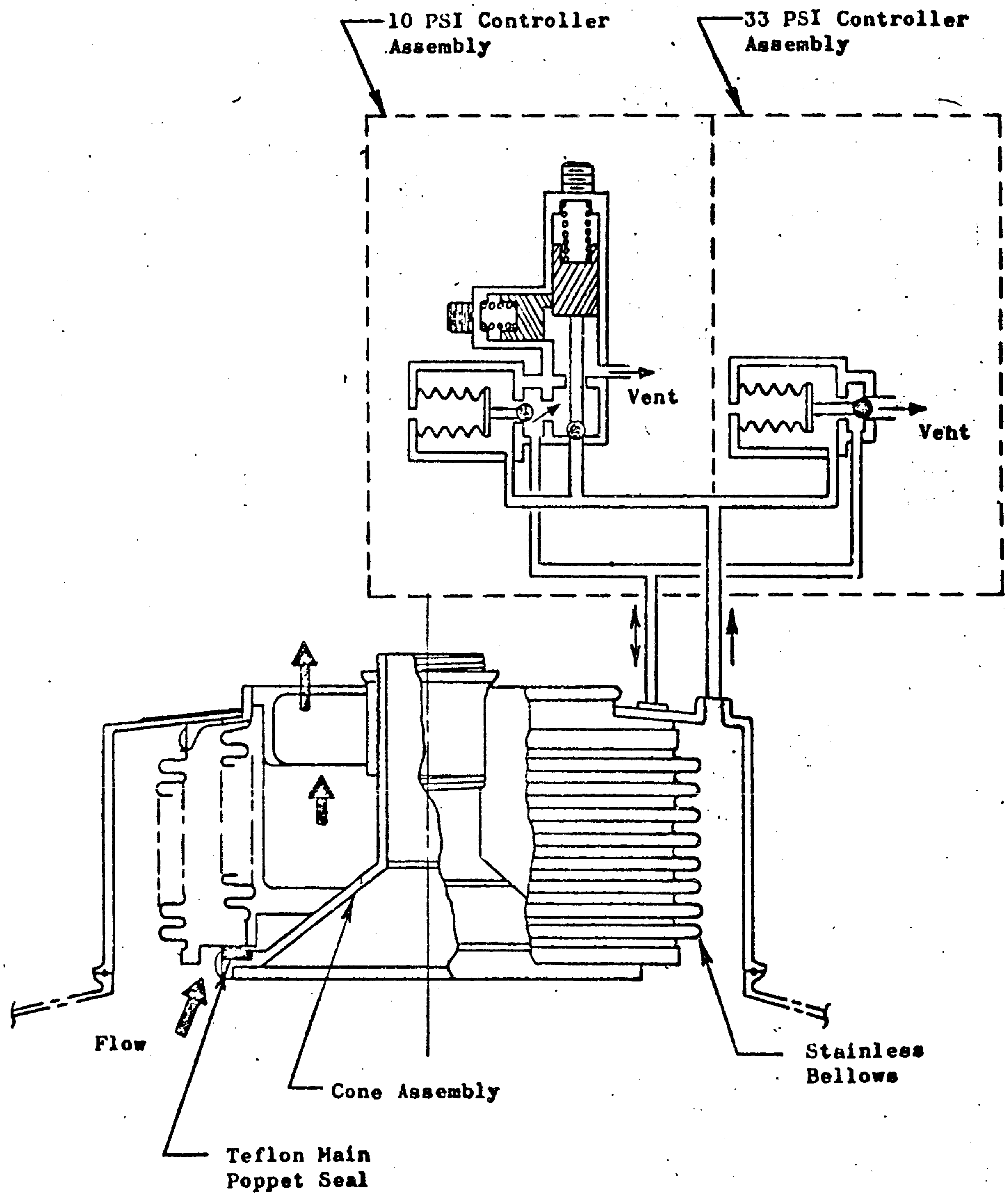



FREQUENCY (CPS)
POWER SPECTRAL DENSITY (G^2/CPS)
RANDOM VIBRATION ENVELOPE
FOR COMBINATION WITH SINUSOIDAL VIBRATION (FIG. II)
FIGURE III
18 db/OCT OR GREATER
0.125
0.0625
18 db/OCT
18 db/OCT


COMBINED SINUSOIDAL & RANDOM
SINUSOIDAL CYCLING RATE
FIGURE IV
2 MINUTES/OCTAVE
SINUSOIDAL FREQUENCY (CPS)
TIME (MINUTES)
2000
1000
500
100
50
40
30
20
10
5
0
10
20
30
SEMI-LOGARITHMIC 46 6213

SCHEMATIC FOR -1 RELIEF VALVE

FIGURE V



GENERAL DYNAMICS
Convair Division

DESIGN REVIEW REPORT

DESIGN REVIEW REPORT NO. 696-2-3245-97

TITLE: FLOX Relief Valve

DATE OF REVIEW: 31 August 65

RESPONSIBLE GROUP: Pneumatics Design, 664-0

REF. DOCUMENTS/DRAWING: Report GD/C-BJB65-009

SYSTEM: FLOX Airborne Pneumatics

ECP 8459

Conclusion:

With due consideration of the direction identified by this Review, the Preliminary Design of "Rupture Disc" FLOX Relief Valve satisfactorily meets the ground rules and requirements of Sales Order (S.O.) 458-1-19, (Task Order #5 to the -3245 Contract) and subsequent direction. The other proposed concepts were eliminated from further consideration. The Preliminary Design presented is documented by Convair Report GD/C-BJB65-009 of which this report is a part.

Design Review Chairman D R Thomas (2.5) Date 13 SEPT '65

Responsible Group K. L. Gray Date 15 SEPT 65

Design Review Group (b) L. W. Standley Date 15 Sept 65

NO.	ACTION ITEM	ACTION BY	SCHEDULE

Actions Items - None

Direction:

1. The rupture disc concept is approved, and the requirement for overboard venting will be reserved for future resolution.

GENERAL DYNAMICS
Convair Division

DESIGN REVIEW REPORT

PURPOSE:

In compliance with the S.O. and Division Policy, this Design Review was held. The objective of the Review was to evaluate the technical adequacy and accuracy of the preliminary design. The further objective war to demonstrate to the Customer this technical adequacy, as well as Convair's compliance to the technical requirements of the contract.

PRESENTATION:

Mr. Gray of the Pneumatics Design Group gave the main presentation. This presentation summarized the material found in the presentation handout which is a significant portion of the Final Report (GD/C-BJB65-009) (A copy of the handout is on file with the master of this Design Review Report.)

The Report and the presentation encompassed the conceptsof a FLOX tank relief valve authorized by the S.O. They include:

a) A preliminary design using a modified GD/C Atlas oxidizer boil off valve (BOV) (P/N 55-80209) &

b) A new all metal relief valve. Three new concepts were presented which proposed:

   1) An all metal optical flat seat concept
   2) An all metal lapped spherical seat concept
   3) A rupture disc assembly concept backed up by a simple relief valve

This presentation supported the decision of an earlier review (about 2 August) and subsequent Customer direction to drop the BOV, optical flat seat and the lapped spherical seat concepts. The majority of the Design Review was spent on the favored rupture disc concept.

DISCUSSION HIGHLIGHTS:

1. The FLOX tank pressure relief valve is a pressure limiting device for relieving FLOX tank pressure when it exceeds the prescribed pressure during engine start, launch, powered flighh and coast periods. Its capacity is based on its capability to relieve excessive tank pressure due to any failure within the regulator, provided the regulator's flow limiter is still functioning.

DISCUSSION HIGHLIGHTS: (Continued)

The rupture disc assembly will be designed to rupture at approximately 36.5 ±1.5 psig. The spring loaded back up poppet relief valve will be designed to crack/reseat above 32.1 psig and full flow at 34.7 psig.

2. The question was raised as to when, during a countdown or flight, could the relief valve operate.

On the ground, the relief valve will not see FLOX tank pressures above 30 psi until after commit start when vehicle pressurization goes internal, and to flight pressures. This is about two minutes before lift off. However, if excessive pressures are observed in this period, a "Pneumatics Emergency" will occur which will automatically return the pressurization to standby pressures (10 psi) under the control of the AGE Pressuization Control Unit (PCU). This takes about 4 seconds.

If the rupture disc bursts in that brief period, a decision would be required on whether or not to fly with a ruptured relief disc. The back up poppet relief valve will still maintain safe flight pressure, but with some FLOX vapor leakage.

In flight, if excessive pressure caused the rupture disc to burst, tank integrity would be maintained by the poppet relief valve, but leakage would occur continuously from the time of failure.

3. The question of leakage dissipation was then discussed.

It was first recognized that a significant advantage of the rupture disc concept was that no leakage would occur during normal operation.

The original system concept to handle leakage was to exhaust the leakage into the BOV duct. This duct was to be open to atmosphere after lift off and separation from the BOV umbilical. Currently, however, one alternate for the BOV umbilical disconnect concept is to have a sealed closure on the A/B half of the disconnect. This would not allow the relief valve to relieve. (See Convair Report GD/C-RHV65-004 and Design Review Report 696-2-3245-98).

The solution is to provide the relief valve with its own overboard vent line. This could create the requirement for a relief valve umbilical.

It was concluded that the problem did not impact the relief valve concept and that future trade off requirements could negate any attempt to solve the problem now. (Direction #1).

DESIGN REVIEW REPORT

DISCUSSION HIGHLIGHTS: (Continued)

4. Mr. Braun, NASA, asked what confidence Convair had in the ability to produce a reliable rupture disc of the required size that would fail within the pressure tolerances required.

   Mr. Gray stated that while there is no disc presently available and qualified to meet these requirements, the vendors contacted (Calmec for one) stated there should be no significant problem in this area. Vendors have produced and qualified rupture discs in the general sizes and pressure ranges. Several vendors were mentioned by Mr. Gray, and Mr. Braun mentioned one or two.

5. In addition to the above, Convair pointed out that the following considerations have been incorporated into the design concept.

   a) The materials selected for the relief valve are compatible with a fluid medium of liquid oxygen and fluorine combined in any mixture ratio.

   b) Only metallic seals, gaskets and "O" rings are employed for separable closures exposed to FLOX.

   c) Carbon and rubber materials are not being used in the design.

   d) The design minimizes external and internal leakage.

   e) Ease of cleaning, purging, inspection and contamination control is a prime consideration in this design.

   f) The design is in conformance with the Atlas/Centaur system and Atlas/Centaur environmental specifications (GD/C Report No. 69-00202, Amendment B, dated January 21, 1964),

   g) No lubricants are used.

   h) No cadmium plating is used in the design of any part of the relief valve.

   i) Relief valve design is as simple as possible, and still perform the necessary functions. Threaded parts are held to a minimum.

GENERAL DYNAMICS
Convair Division

DESIGN REVIEW REPORT

DESIGN REVIEW REPORT NO. 696-2-3245-97

ATTENDEES:

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Major J. M. Mickelson	AF-71
Major G. L. Claypool	SSD-SSVZE (5)

TEST REQUIREMENTS

OXIDIZER TANK RELIEF VALVE

FLOX-ATLAS, AIRBORNE

8 NOVEMBER 1965

CONTRACT NUMBER NAS3-3245

TCP 8459 NASA/LeRC

TASK ORDER #5

PREPARED BY: A. M. Colvin
A. M. COLVIN
DESIGN SPECIALIST

APPROVED BY: D. L. Gray
D. L. GRAY
SR. DESIGN ENGINEER

APPROVED BY: D. L. Hobart
D. L. HOBART
DESIGN GROUP ENGINEER

APPROVED BY: for
W. A. ROBERTS
ASS'T PROJECT ENGINEER
FLOX PROGRAM OFFICE

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1.0 INTRODUCTION

1.1 Scope

This document specifies the testing required on the FLOX-Atlas oxidizer tank pressure relief unit to demonstrate conformance to the performance specification. Ref. (General Dynamics Convair Report No. BJB65-009).

The relief unit consists of a rupture disc for primary pressure relief and a spring loaded poppet relief valve downstream of the rupture disc.

2.0 TEST CONDITIONS

2.1 Atmospheric Conditions

Unless otherwise specified herein, all tests shall be performed at an atmospheric pressure between 28 inches and 32 inches of mercury, a temperature between +60°F and 95°F, and a relative humidity of not more than 90%. Data from tests performed at other than the atmospheric conditions specified shall include corrections for instrument compensation.

2.2 Tolerances

The maximum allowable tolerances on test conditions shall be as follows:

a) Temperature	±4°F, or 6% of temp. span whichever is greater.
b) Barometric Pressure	±5%
c) Relative Humidity	±10%
d) Vibration Amplitude	±10%
e) Vibration Frequency	±2%
f) Acceleration	±10%
g) Shock	±10%
h) Volume	±3%
i) Pressure	±3% *
j) Flow	±3%

* Ullage pressure measurement shall be certified to a readout tolerance of ±0.32 psi (±1% of 32 psig).

2.0 TEST CONDITIONS (continued)

2.3 Measurements

All measurements shall be made with instruments whose accuracies have been currently certified.

2.4 Adjustments and Repairs During Tests

No adjustment, maintenance, or repairs of the test specimen shall be allowed during the test program. Exceptions shall be made when in the opinion of designated personnel, adjustments, repairs, or maintenance are not due to faults in design, workmanship, materials, or to the test conditions imposed.

2.5 Temperature Stabilization

Temperature stabilization has been reached when the temperature of the largest centrally located mass of the test specimen does not vary more than 5°F from the temperature ambient to the equipment.

3.0 CLASSIFICATION OF TESTS

3.1 Individual Acceptance Tests

3.1.1 Rupture Disc - Three rupture discs shall be manufactured for each one that is to be delivered and subjected to the following tests.

a) Examination of Product (3 discs)

b) Proof Pressure (3 discs)

c) Burst (2 discs) - Burst number 1 disc at +160°F and number 3 disc at -30°F. Burst pressure shall be 36.5 ± 1.0 psig.

3.1.2 Relief Valve - Each relief valve shall be subjected to the following tests.

a) Examination of Product

b) Proof Pressure

c) Flow

3.2 Preproduction Tests

3.2.1 Relief Valve - One (1) test specimen shall be subjected to the Fluorine Compatibility Tests specified in paragraph 3.2.1.1 and one (1) test specimen shall be subjected to the Operational Tests specified in paragraph 3.2.1.2. The test specimens shall have been subjected to the Individual Acceptance Tests before being subjected to the Preproduction Tests.

3.0 CLASSIFICATION OF TESTS (continued)

3.2.1.1 Fluorine Compatibility - Unit Number 1

a) Examination of Product

b) Proof Pressure

c) Passivation

d) Flow Cycles

e) Leakage

3.2.1.2 Operational - Unit Number 2

a) Examination of Product

b) Proof Pressure

c) Extreme Temperature

d) Vibration

e) Acceleration

NOTE: Do not subject this relief valve to the burst test until test (c) of paragraph 3.2.2 (Endurance) has been accomplished.

f) Burst

3.2.2 Rupture Disc - Fifty (50) delivered rupture discs that have been subjected to the Individual Acceptance Tests shall be tested according to the following test schedule.

a) Examination of Product (50 discs)

b) Proof Pressure (50 discs)

c) Endurance - Relief valve test specimen number 2 shall be installed in the rupture disc burst test setup.

NOTE: This test to be performed after accomplishing tests (a) thru (e) of paragraph 3.2.1.2 on relief valve specimen number 2.

4.0 TEST PROCEDURES

4.1 Examination of Product

Visually examine each test unit in order to determine that the specimen meets the requirements of workmanship, identification markings, external dimensions, finish, cleanliness, and proper inspection approval. The specimen shall be free of tool marks and any damage resulting from testing and handling. The specimen cleanliness shall be maintained throughout the test program. When not in test, each test specimen shall be properly packaged and placed in a clean polyethylene bag to prevent contamination.

4.2 Proof Pressure Test

4.2.1 Rupture Disc -

a) Install the test specimen in a rupture disc assembly per manufacturer's instructions.

b) Install the rupture disc assembly in the test setup shown in Figure I.

c) Slowly pressurize the test specimen inlet port to 33.5 $\pm$ 0.5 psig with ambient temperature dry helium gas and hold this pressure for three (3) minutes. Measure total leakage by water displacement method for last two (2) minutes. The leakage shall not exceed 5 SCC per hour.

CAUTION: Do not exceed 34 psig at inlet port.

d) Depressurize system and visually examine test specimen for damage or deformation. No damage or deformation allowed.

4.2.2 Relief Valve -

a) Install the test specimen in the test setup shown in Figure V.

b) Slowly pressurize the test specimen inlet port to 53 psig with ambient temperature dry helium gas and hold this pressure for one (1) minute.

c) Relieve the pressure and visually examine the test specimen for damage or deformation.

4.3 Relief Valve Flow Test

a) Install the test specimen in the test setup shown in Figure VI.

4.0 TEST PROCEDURES (continued)

4.3 continued

b) Instrumentation - Recorder channel identification and scale ranges shall be as folllews: (Paper speed 2.5 mm/sec)

CHANNEL NO.	CHANNEL IDENTIFICATION	SCALE RANGE
1	Ullage Tank Pressure	30.0 - 40.0 psig
2	Flow Control Valve Inlet Pressure	0 - 5000 psig
3	Test Specimen Temperature	-100 to +200°F.

c) Slowly increase ullage tank pressure to 31.5 ±0.5 psig with ambient temperature helium gas.

d) Increase the ullage tank pressure from 31.5 ± 0.5 psig at a rate of 6 to 10 psi per minute with ambient temperature helium gas. Maximum cracking pressure shall be 34.7 psig and minimum reseat shall be 32.1 psig.

e) Decrease ullage tank pressure to 31.5 ± 0.5 psig. Then open solenoid valve rapidly (within 0.5 second) to flow 0.85 ± .05 lbs/sec of ambient temperature helium gas into the ullage for a period of 5 ± 1 seconds, then close solenoid valve within 0.5 second. The maximum tank pressure shall be 36.5 psig and the minimum reseat shall be 32.1 psig.

f) Decrease the ullage tank pressure to 32.1 psig and measure external and internal leakage. The internal leakage shall not exceed 35,000 SCIMS. The external leakage shall not exceed 5 SCC per hour.

4.4 Relief Valve Extreme Temperature

The following test sequence shall be conducted in a temperature chamber in the order specified. A thermocouple shall be placed on good thermal contact on the largest centrally located internal mass within the unit, or in any other location deemed necessary to check temperature stabilization.

a) Install the test specimen in the temperature leakage chamber in the test setup shown in Figure VI and perform a Flow Test.

b) The chamber temperature shall be reduced to minus 65°F, at a rate of 0.75 to 1.25°F per minute, and maintained at this temperature for a period of not less than 8 hours, or until unit temperature stabilizes, whichever is longer. The chamber temperature shall then be raised to minus 30°F and maintained at minus 30°F until the unit temperature stabilizes. While at this temperature perform a Flow Test.

4.0 TEST PROCEDURES (continued)

4.4 continued

c) The chamber temperature shall be increased to +160°F at a rate of 0.75 to 1.25°F per minute, and maintained at this temperature for a period of not less than 8 hours, or until unit temperature stabilizes, whichever is longer. While at this temperature, perform a Flow Test.

d) The chamber temperature shall be reduced to +40°F at a rate of 0.75 to 1.25°F per minute, and maintained at this temperature for a period of not less than 4 hours, or until unit temperature stabilizes, whichever is longer. While at this temperature, perform a Flow Test.

e) Return the chamber temperature to the initial ambient conditions and perform a Flow Test.

4.5 Relief Valve Vibration

a) The vibration test setup is shown in Figure VI.

b) Instrumentation - Instrumentation on recorder channels as required to record ullage tank pressure, flow control valve inlet pressure, and vibration input and output.

c) Align the test specimen in the test setup with its "X" axis aligned along the axis of input vibration.

d) Pressurize the ullage tank to 30.0 ± 0.5 psig with ambient temperature helium gas.

e) While maintaining the ullage tank at 30.0 ± 0.5 psig, commence the slow speed vibration scanning sweep, at frequencies and amplitudes of combined sinusoidal random vibration as shown in Figure II and III, and a sweep period as shown in Figure IV. Note the three most resonant frequency points and perform a crack and reseat per step (d) of paragraph 4.3 measuring the reseat internal leakage for one minute.

f) If at any time during the vibration test, the test specimen malfunctions, hold the vibration frequency and reduce the "G" level until the malfunction is no longer evident. These vibration frequencies and "G" levels shall be recorded on the test data sheet and the scan per step (e) continued.

g) Perform a Flow Test.

h) Align the test specimen in the test setup with its "Y" axis aligned along the axis of input vibration.

i) Repeat steps (d) thru (g).

j) Align the test specimen in the test setup with its "Z" axis aligned along the axis of input vibration.

k) Repeat steps (d) thru (g).

4.0 TEST PROCEDURES (continued)

4.6 Fluorine Compatibility

a) The test setup for the compatibility tests is illustrated in Figure X.

b) Instrumentation - Recorder channel identification and scale ranges for all phases of life testing shall be as follows: (Paper speed 0.5 mm/sec)

CHANNEL NO.	CHANNEL IDENTIFICATION	SCALE RANGE
1	Ullage tank pressure	20.0 - 35.0 psig
2	Specimen inlet pressure	0 - 1000 psig

c) Mount the test specimen in the FLOX clean test setup, and leak check the system while pressurized at 31 psig.

d) Passivate the system in the following manner:

1. Open valve #3.

2. Open valve #4 until gage #6 indicates relief valve is relieving.

3. Close valve #4, open valve #2.

4. Open valve #1 and #5 and flow F_2 through the system into the disposal at a slow rate for approximately 2 minutes.

5. Close valve #3, adjust valve #1 as required to increase the system pressure according to the following schedule:

   5 psig for 20 minutes
   10 psig for 20 minutes
   15 psig for 20 minutes
   20 psig for 20 minutes
   25 psig for 20 minutes
   31 psig for 3 hours

6. Close valve #2 and open valve #3.

4.0 TEST PROCEDURES (continued)

4.6 continued

7. Open valve #1 and #5 and flow through the test specimen for 2 minutes.

8. Close valves #1 and #5, open valve #2.

9. Open valve #4 and purge system for 10 minutes with dry GN_2.

10. Close valve #2 and flow through test specimen for 5 minutes.

11. Measure & record the test specimen crack and reseat pressure on channel #1.

12. Measure leakage at outlet of test specimen with an inlet pressure of 30 ± 0.5 psig.

13. Open valve #2 and vent system pressure to zero psig.

14. Close all valves and remove test specimen.

4.0 TEST PROCEDURES (continued)

4.7 Relief Valve Acceleration

a) The acceleration test setup is shown in Figure VI.

b) Instrumentation - Recorder channel identification and scale ranges shall be as follows: (Paper speed 1 mm/sec)

CHANNEL NO.	CHANNEL IDENTIFICATION	SCALE RANGE
1	Ullage tank pressure	30.0 - 40.0 psig
2	Flow control valve inlet pressure	0 - 5000 psig
3	Acceleration	5.0 - 15.0 G's

c) Mount the test specimen in the test setup with its "X" axis outboard of the centrifuge in order to perform the "X" axis acceleration.

d) Pressurize the ullage tank to 30.0 ± 0.5 psig with ambient temperature helium gas.

e) While maintaining the ullage tank at 30.0 ± 0.5 psig, operate the centrifuge to obtain 10.0 ± 1.0 G.

f) While maintaining 10.0 ± 1.0 G, perform a crack and reseat per step (c) of paragraph 4.3 measuring the reseat internal leakage for one minute.

g) Repeat steps (c) thru (f) with the test specimen mounted in order to perform the X', Y, Y', Z, and Z' acceleration tests.

h) Perform a Flow Test.

4.8 Endurance

The fifty (50) rupture discs shall be serialized sequentially from one to fifty and subjected to life cycling, vibration, and burst testing as follows:

a) Life Cycling - S/N 1, 2, 9, 10, 17, 18, 33, 34, 35, 36, 43, and 44.

b) Vibration - S/N 19 and 20 in the axis through center line of the disc and S/N 31 and 32 in the axis 90° to the center line.

4.0 TEST PROCEDURES (continued)

4.8 continued

c) Burst - S/N 1 thru 25 at a pressure rise of one (1) psi/sec and S/N 26 thru 50 at a pressure rise of forty (40) psi/sec with the following temperatures and pressurization gas.

S/N	Pressurization Gas	Temperature
1 thru 8	Nitrogen	+160°F
9 thru 16	Nitrogen	- 30°F
17 and 20	Nitrogen	+ 70°F
*21 thru 30	Fluorine	+ 70°F
31 and 34	Nitrogen	+ 70°F
35 thru 42	Nitrogen	- 30°F
43 thru 50	Nitrogen	+160°F

*CAUTION: S/N 21 thru 30 must be cleaned and passivated before burst.

4.8.1 Life Cycling -

a) Install the rupture disc in the rupture disc assembly per manufacturer's instructions.

b) Install the rupture disc assembly in the test setup as shown in Figure VII.

c) Instrumentation - Recorder channel identification and scale ranges shall be as follows: (Paper speed 2.5 mm/sec)

CHANNEL NO.	CHANNEL IDENTIFICATION	SCALE RANGE
1	Ullage tank pressure	0 - 40 psig

d) Cycle the ullage tank pressure from 10.0 $\pm$ 5.0 psig to 30.5 $\pm$ 1.0 psig to 10.0 $\pm$ 5.0 psig with ambient temperature nitrogen gas for 200 cycles, at a rate of 30 $\pm$ 15 cycles per hour. Measure total leakage after each 50 cycles of operation with ullage tank pressure at 30.5 $\pm$ 1.0 psig. The ullage tank pressure rise rate shall not exceed 1 psi/sec.

4.0 TEST PROCEDURES (continued)

4.8.2 Vibration

a) Install the rupture disc in the rupture disc assembly per manufacturer's instructions.

b) Install the rupture disc in the test setup as shown in Figure I with instrumentation as required.

c) Instrumentation - Instrumentation on recorder channels as required to record vibration input and output.

d) Increase pressure to 30.5 ± 1.0 psig and commence the slow speed vibration scanning sweep, at frequencies and amplitudes of combined sinusoidal random vibration as shown in Figure II and III and a sweep period as shown in Figure IV. Measure leakage during the entire scan. Leakage shall not exceed 5 SCC per hour.

4.8.3 Burst

a) Install the rupture disc in the rupture disc assembly per manufacturer's instructions.

b) Install the rupture disc assembly in the test setup as shown in Figure IX.

c) Instrumentation - Recorder channel identification and scale ranges shall be as follows: (Paper speed 2.5 mm/sec)

CHANNEL NO.	CHANNEL IDENTIFICATION	SCALE RANGE
1	Ullage tank pressure	0 - 50 psig
2	Rupture disc assy temperature	-50 to +200°F

d) With the setting of the flow control valve and the test specimen temperature per paragraph 4.8c, increase the ullage tank pressure until rupture disc bursts. Burst pressure shall be 36.5 ± 1.5 psig.

CAUTION: Test system must be passivated before performing the burst test on S/N 21 thru 30 with fluorine gas.

4.0 TEST PROCEDURES (continued)

4.9 **Burst**

4.9.1 **Relief Valve** -

a) Install the test specimen in the test setup shown in Figure VIII.

b) Increase inlet port pressure to 70 psig and hold for 3 minutes. There shall be no evidence of rupture.

c) Increase inlet port pressure to 100 psig or until test specimen ruptures.

d) If test specimen ruptures below 100 psig, record rupture pressure.

4.9.2 **Rupture Disc** -

a) Install the rupture disc in the rupture disc assembly per manufacturer's instructions.

b) Install the rupture disc assembly in the test setup as shown in Figure VIII.

c) Instrumentation - Recorder channel identification and scale ranges shall be as follows: (Paper speed 2.5 mm/sec)

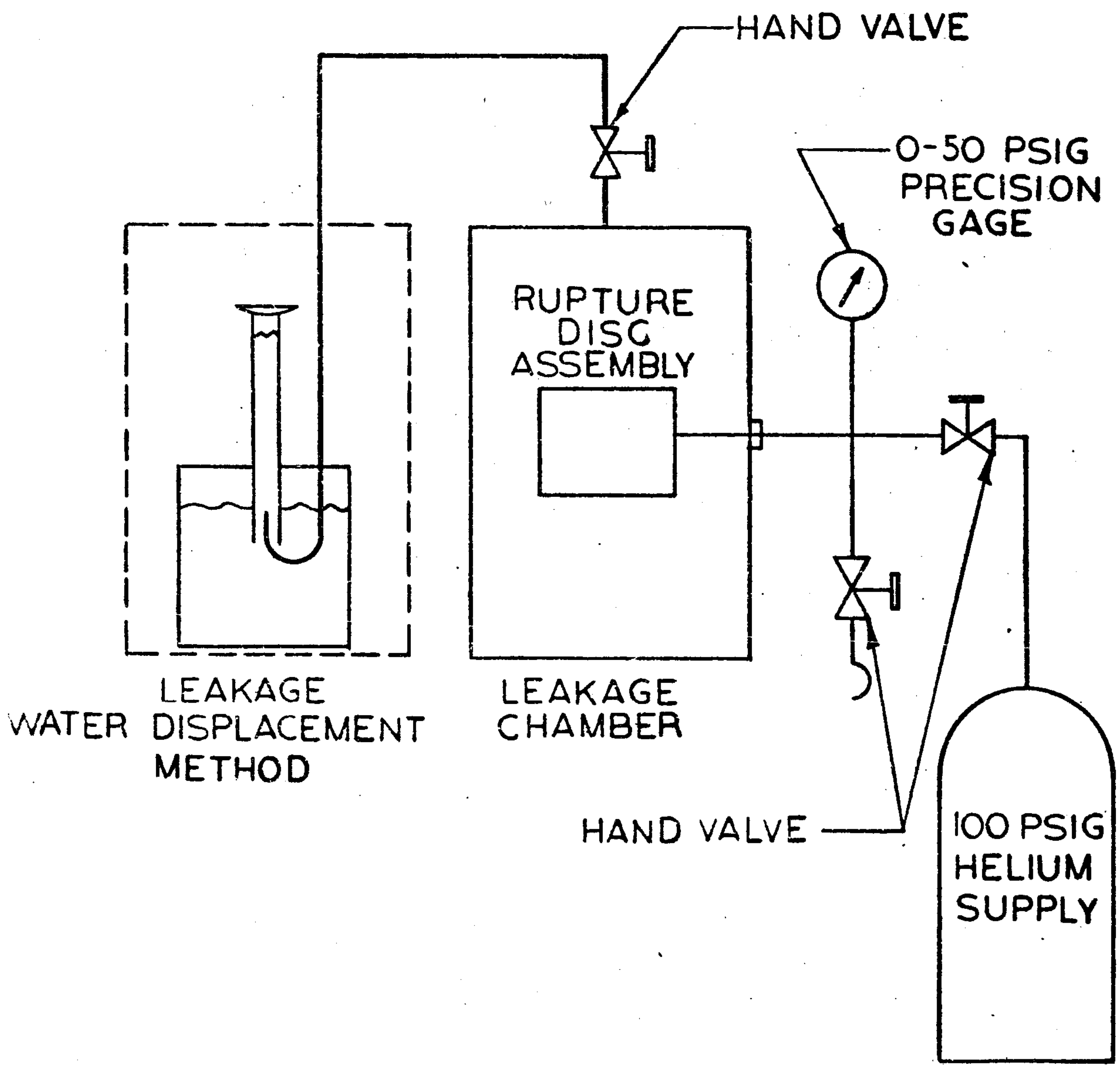
CHANNEL NO.	CHANNEL IDENTIFICATION	SCALE RANGE
1	Inlet port pressure	0 - 50 psig
2	Test specimen temperature	-50 to +200°F

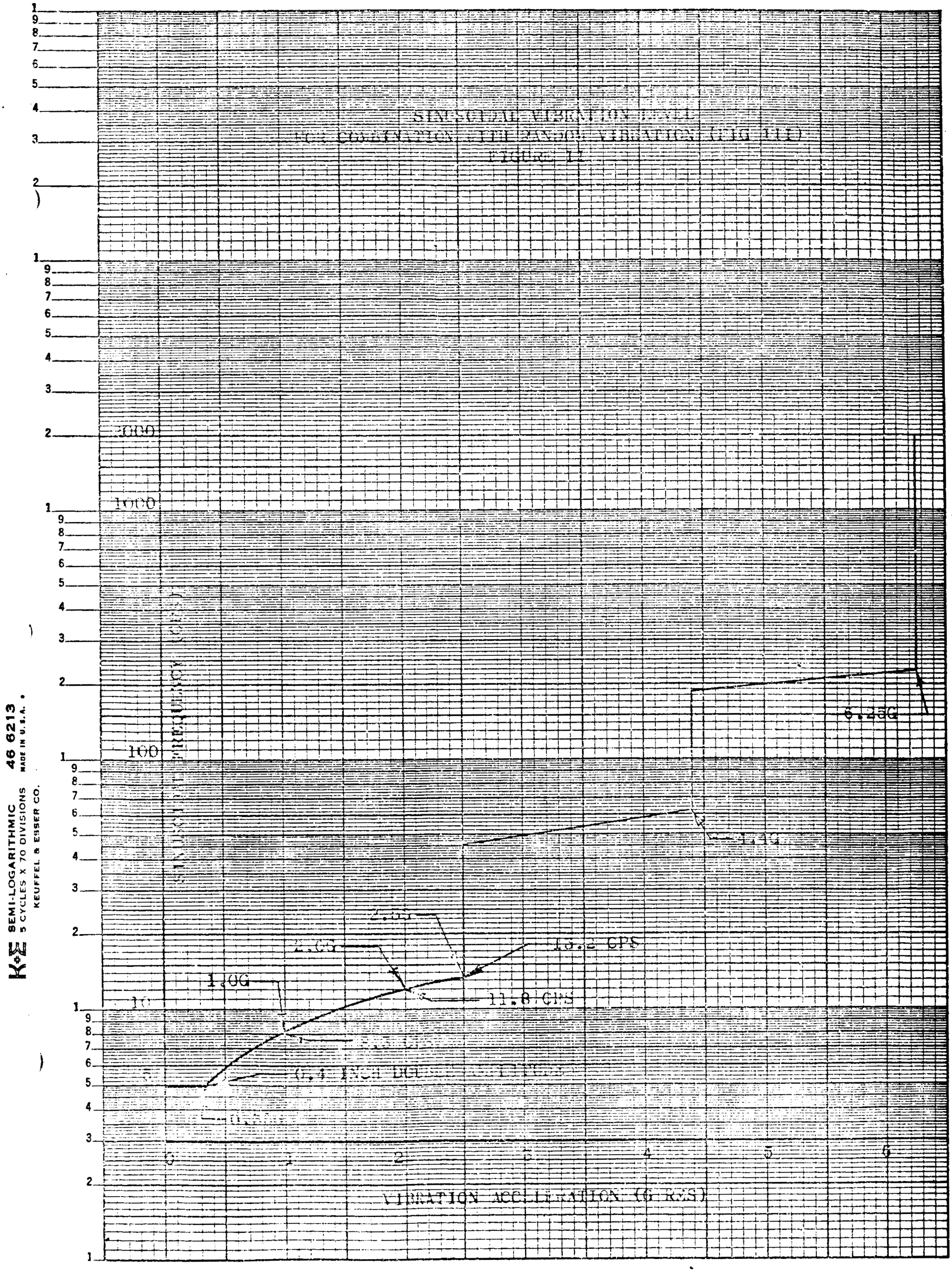
d) Slowly increase the inlet pressure until test specimen ruptures. Rupture pressure shall be 36.5 ± 1.0 psig.

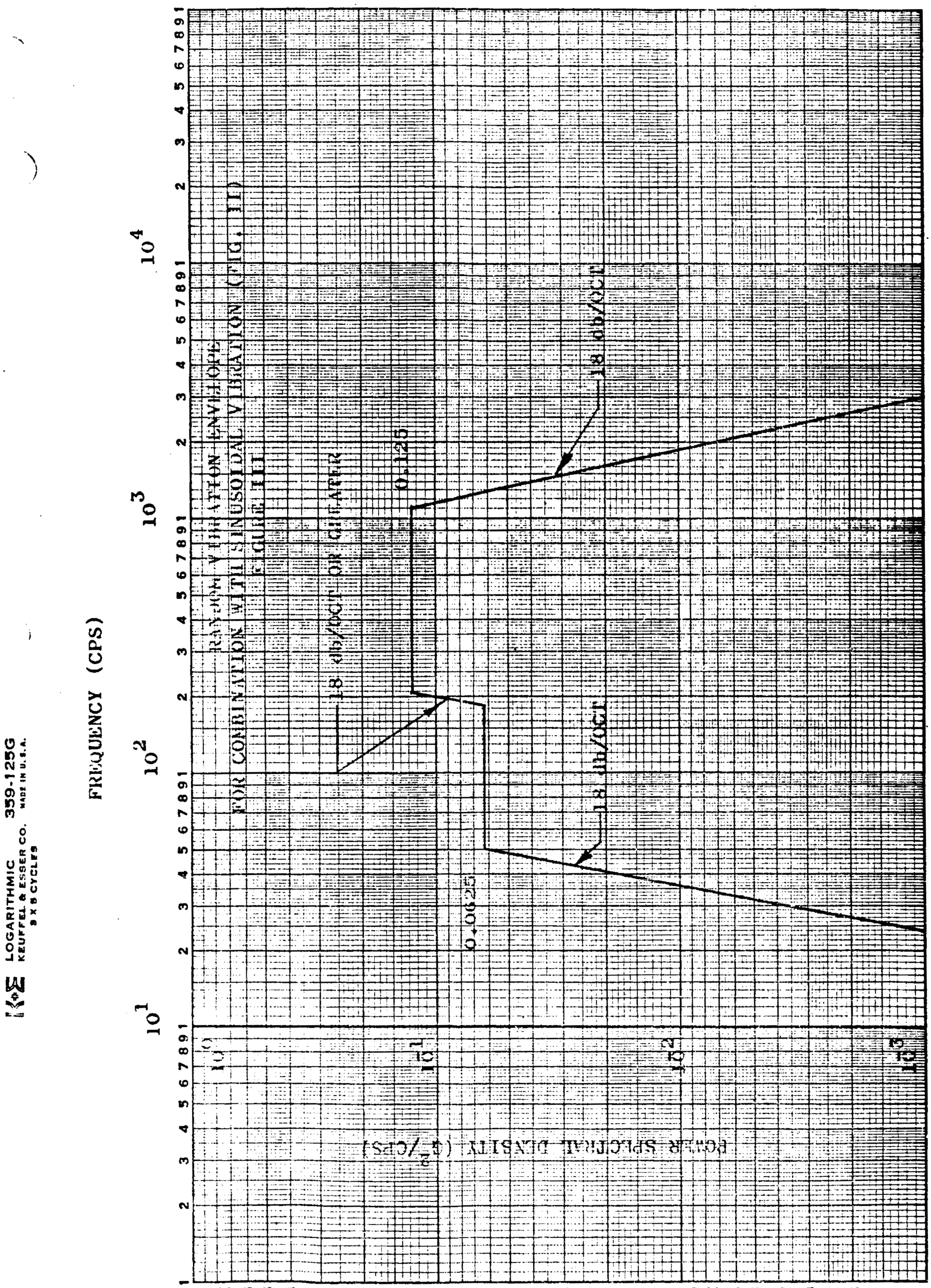
SCHEMATIC — RUPTURE DISC

PROOF PRESSURE AND ENDURANCE VIBRATION TEST

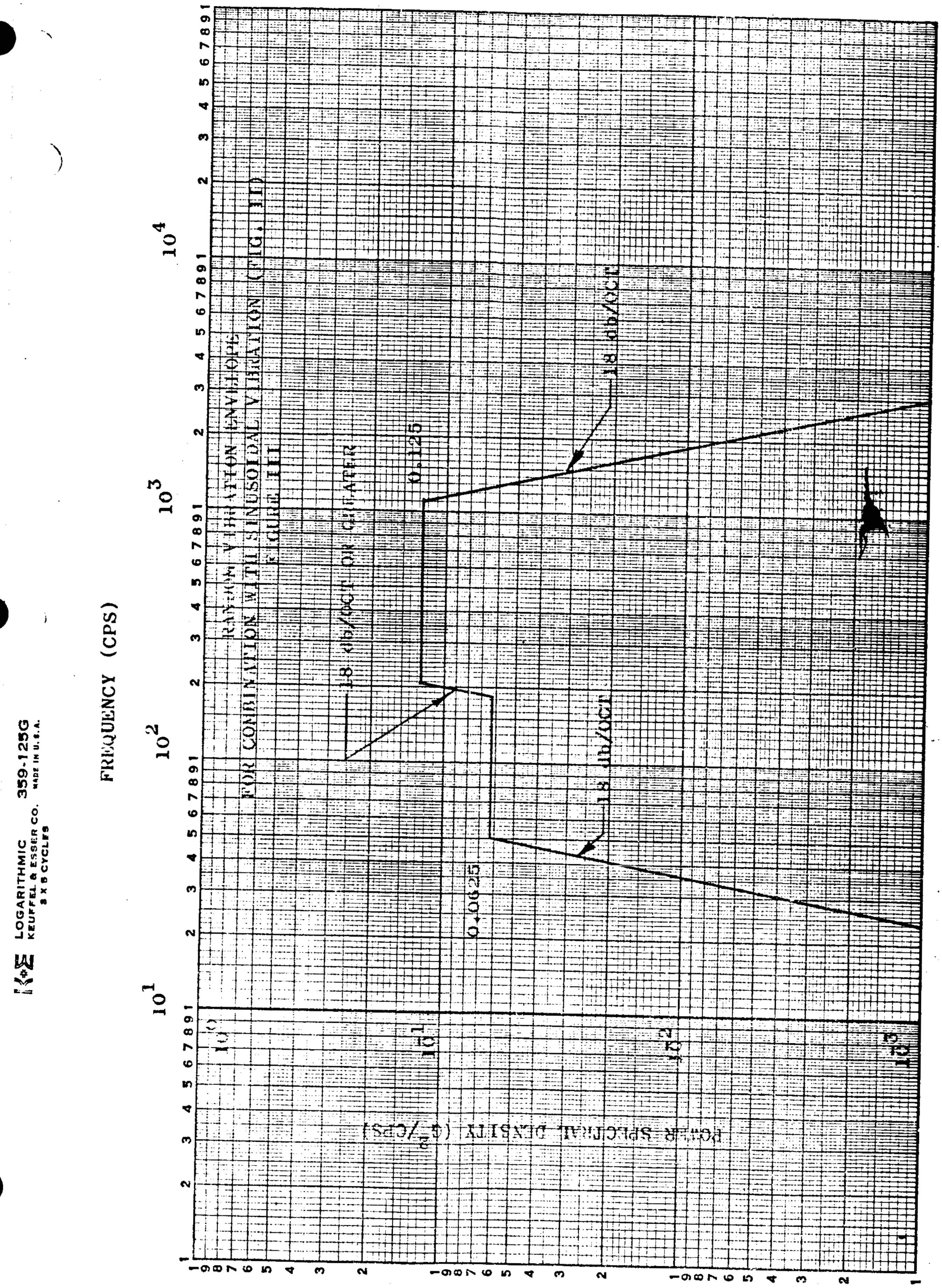
FIGURE I

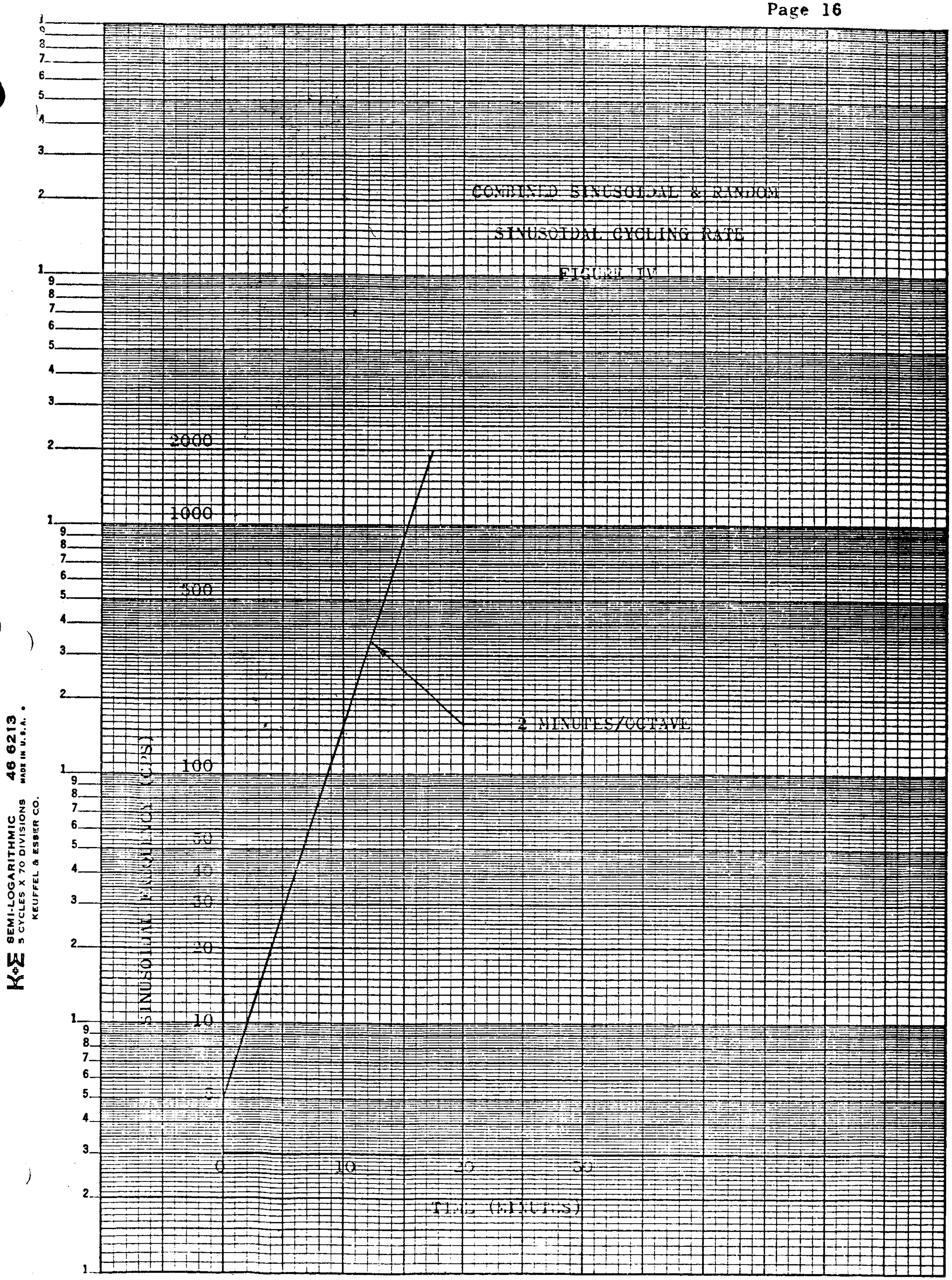



1000
100
10
6.25G
1.0G
11.8 CPS
2
3
4
5
6
KE SEMI-LOGARITHMIC 46 6213
5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.
MADE IN U.S.A.



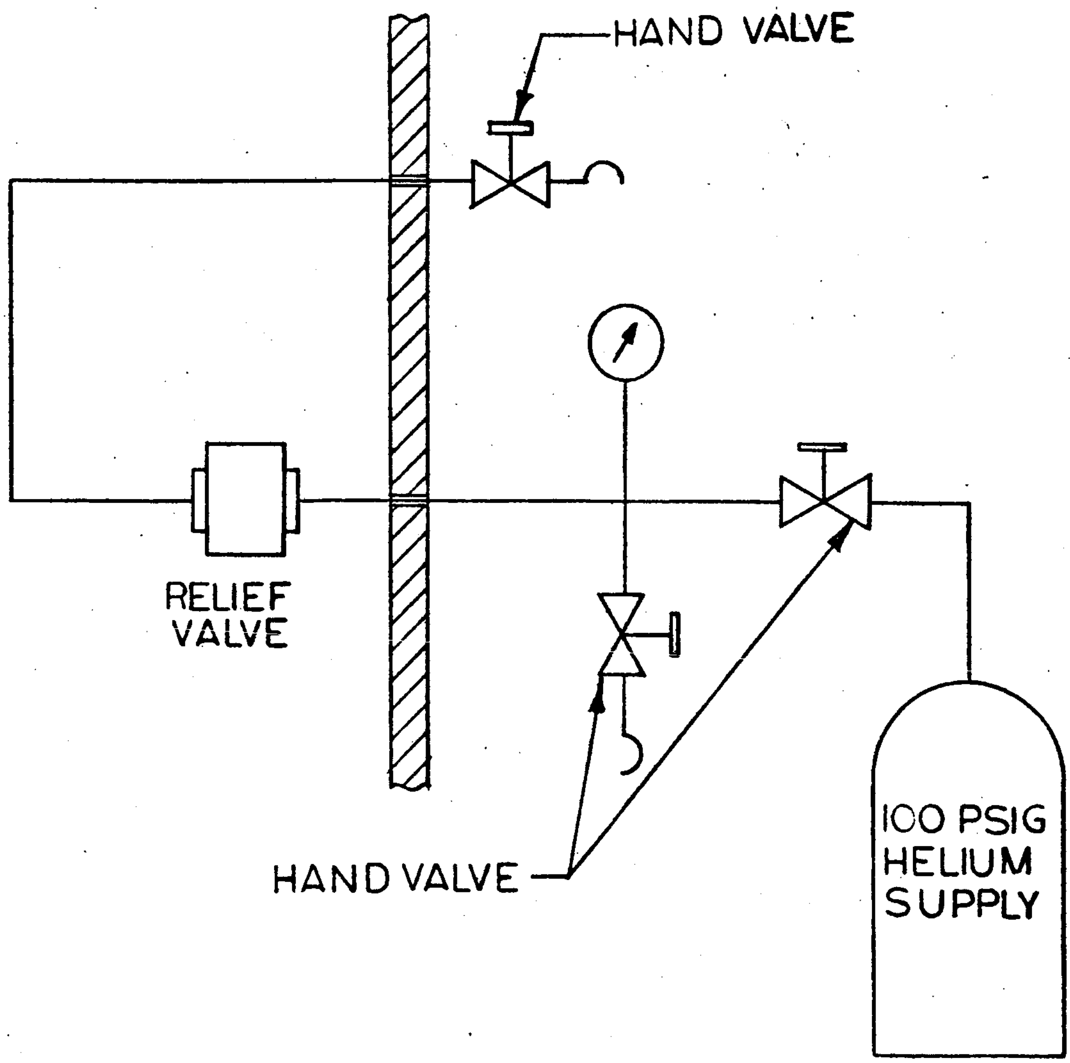
RANDOM VIBRATION ENVELOPE
FOR COMBINATION WITH SINUSOIDAL VIBRATION (FIG. II)
FIGURE III
18 db/OCT OR GREATER
0.125
18 db/OCT
18 db/OCT
0.0625
FREQUENCY (CPS)
POWER SPECTRAL DENSITY (g²/CPS)


RANDOM VIBRATION ENVELOPE
FOR COMBINATION WITH SINUSOIDAL VIBRATION (FIG. III)
FIGURE III
FREQUENCY (CPS)
POWER SPECTRAL DENSITY (g^2/CPS)
18 db/OCT OR GREATER
0.125
18 db/OCT
0.0625
18 db/OCT
LOGARITHMIC
KEUFFEL & ESSER CO.
359-125G
MADE IN U.S.A.
3 X 5 CYCLES


COMBINED SINUSOIDAL & RANDOM
SINUSOIDAL CYCLING RATE
FIGURE IV
2000
1000
500
100
50
40
30
20
10
2 MINUTES/OCTAVE
SINUSOIDAL FREQUENCY (CPS)
0
10
20
30
TIME (MINUTES)
K+E SEMI-LOGARITHMIC 46 6213
5 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

RELIEF VALVE PROOF PRESSURE TEST SCHEMATIC

FIGURE V

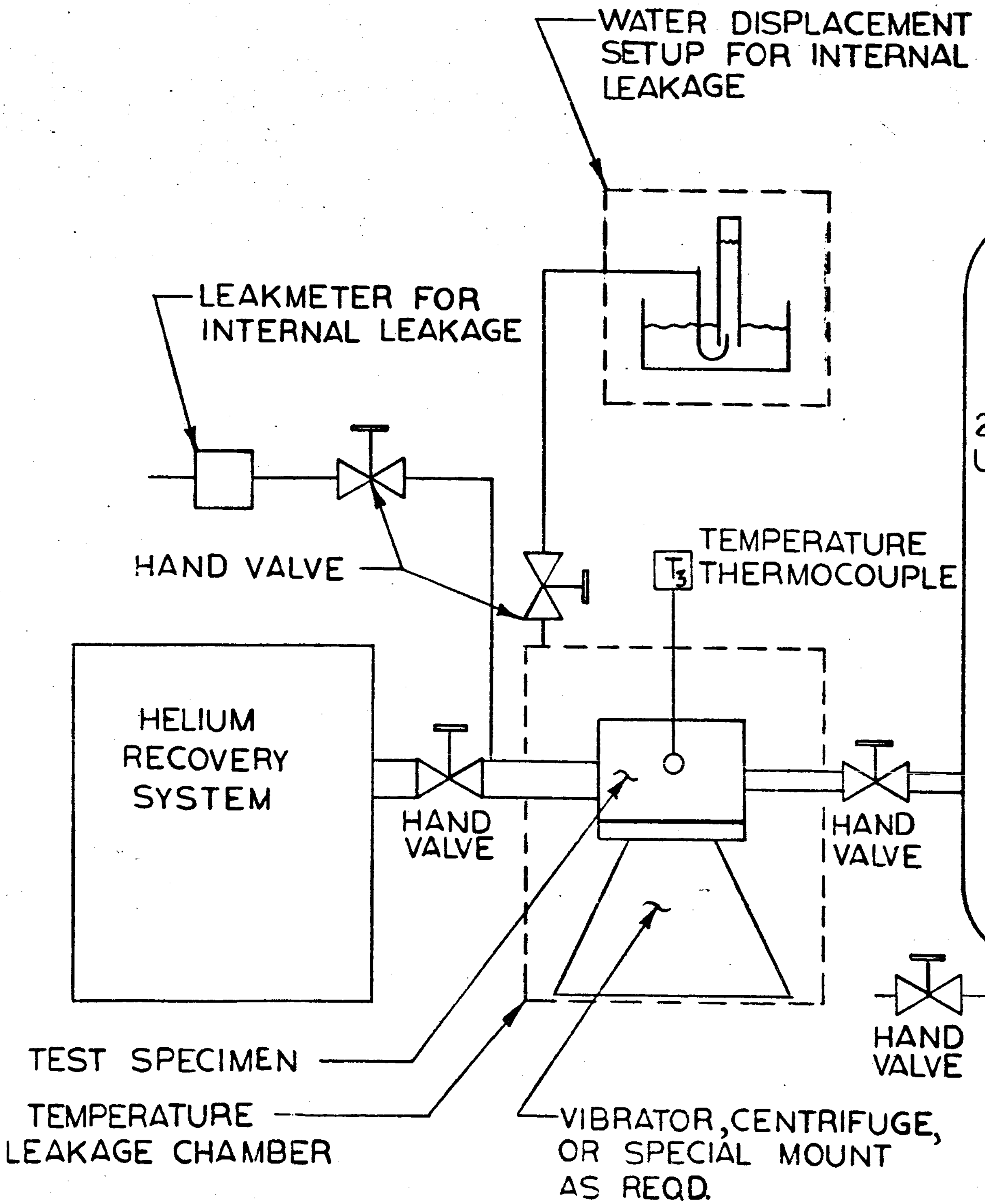


18

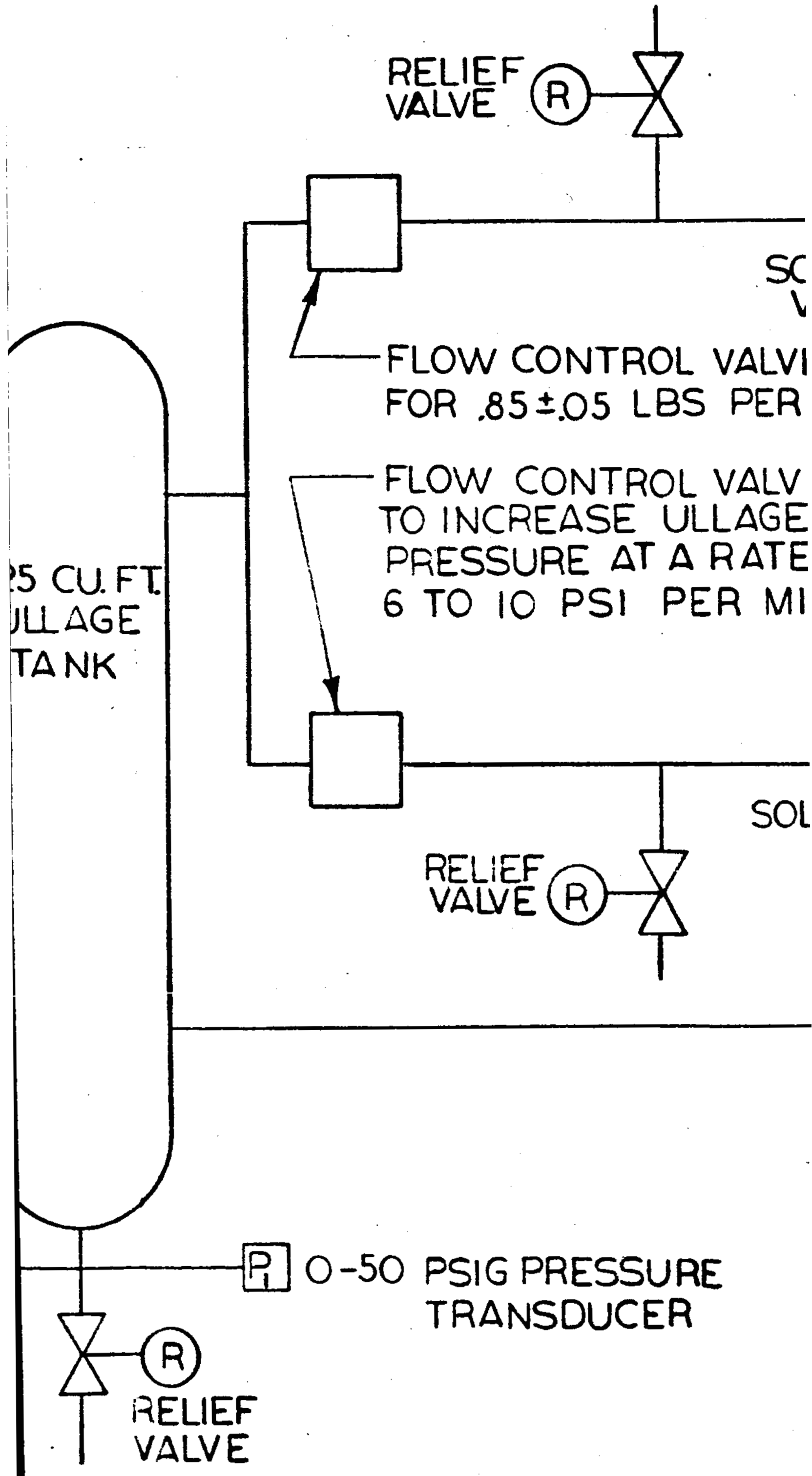
SCH

RELIEF VAL

FLOW, EXTREME TEMPERATU

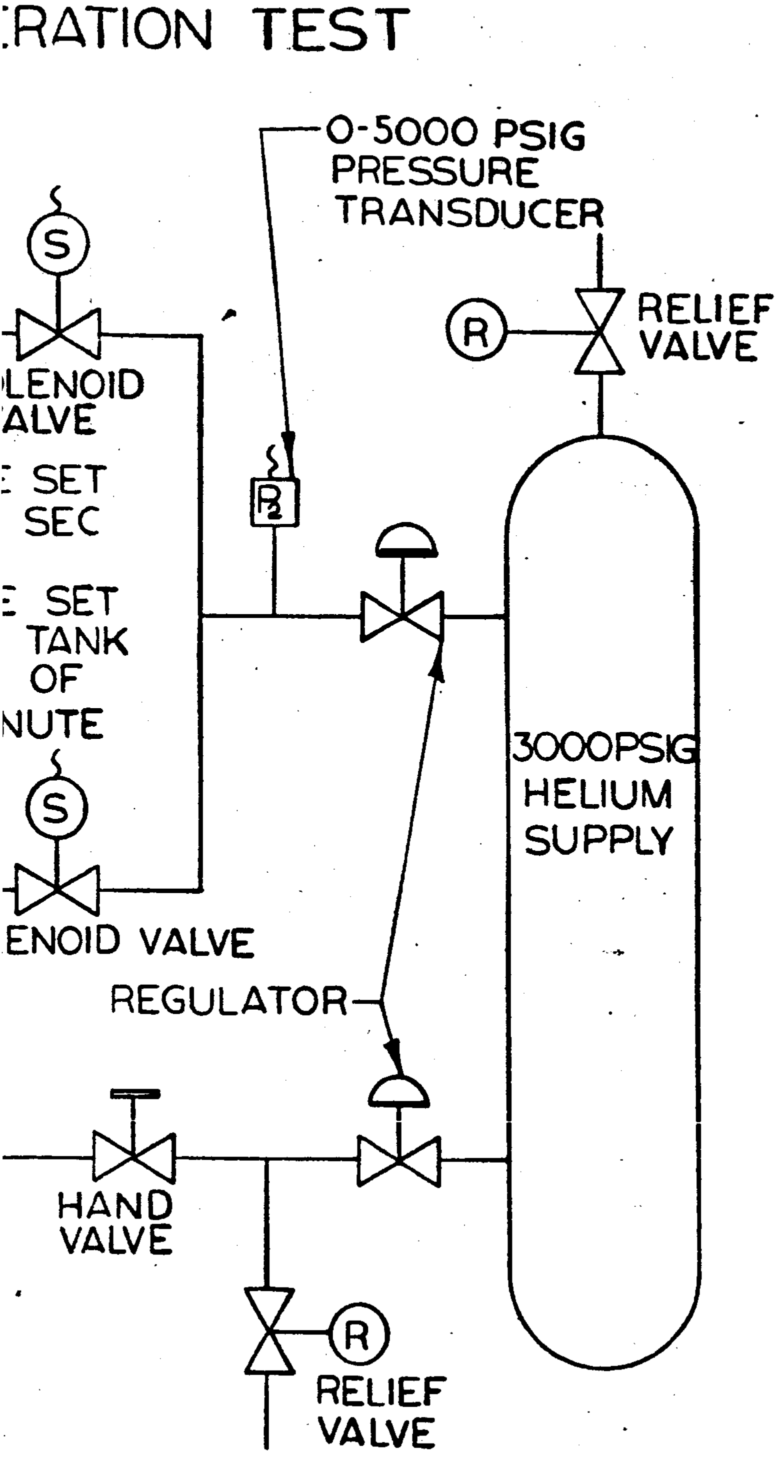


IEMATIC
'E TEST SETUPS
JRE, VIBRATION, AND ACCELE



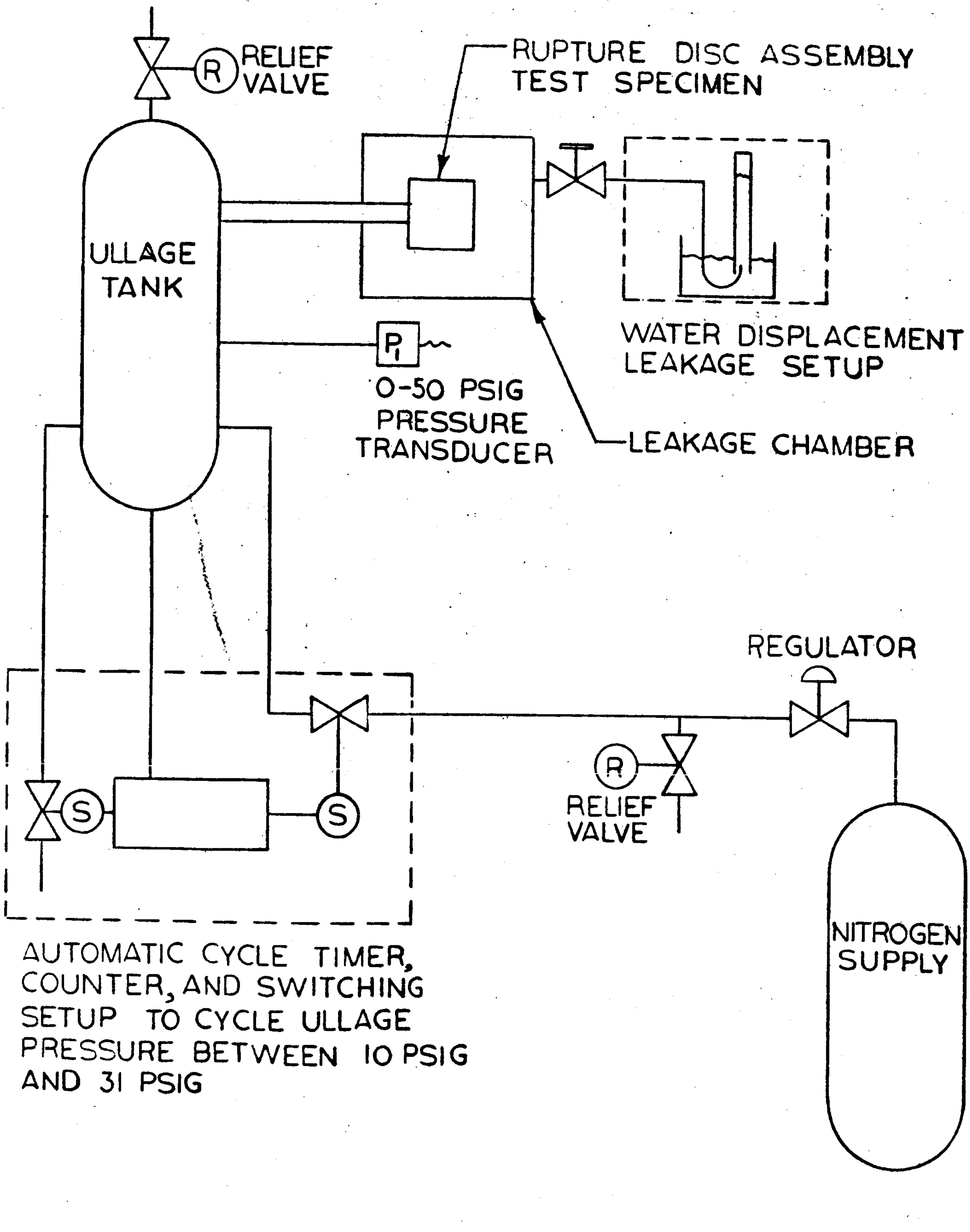
2

FIGURE VI


:RATION TEST
0-5000 PSIG
PRESSURE
TRANSDUCER
RELIEF
VALVE
R
S
LENOID
ALVE
: SET
SEC
: SET
TANK
OF
NUTE
P2
3000PSIG
HELIUM
SUPPLY
S
ENOID VALVE
REGULATOR
HAND
VALVE
R
RELIEF
VALVE

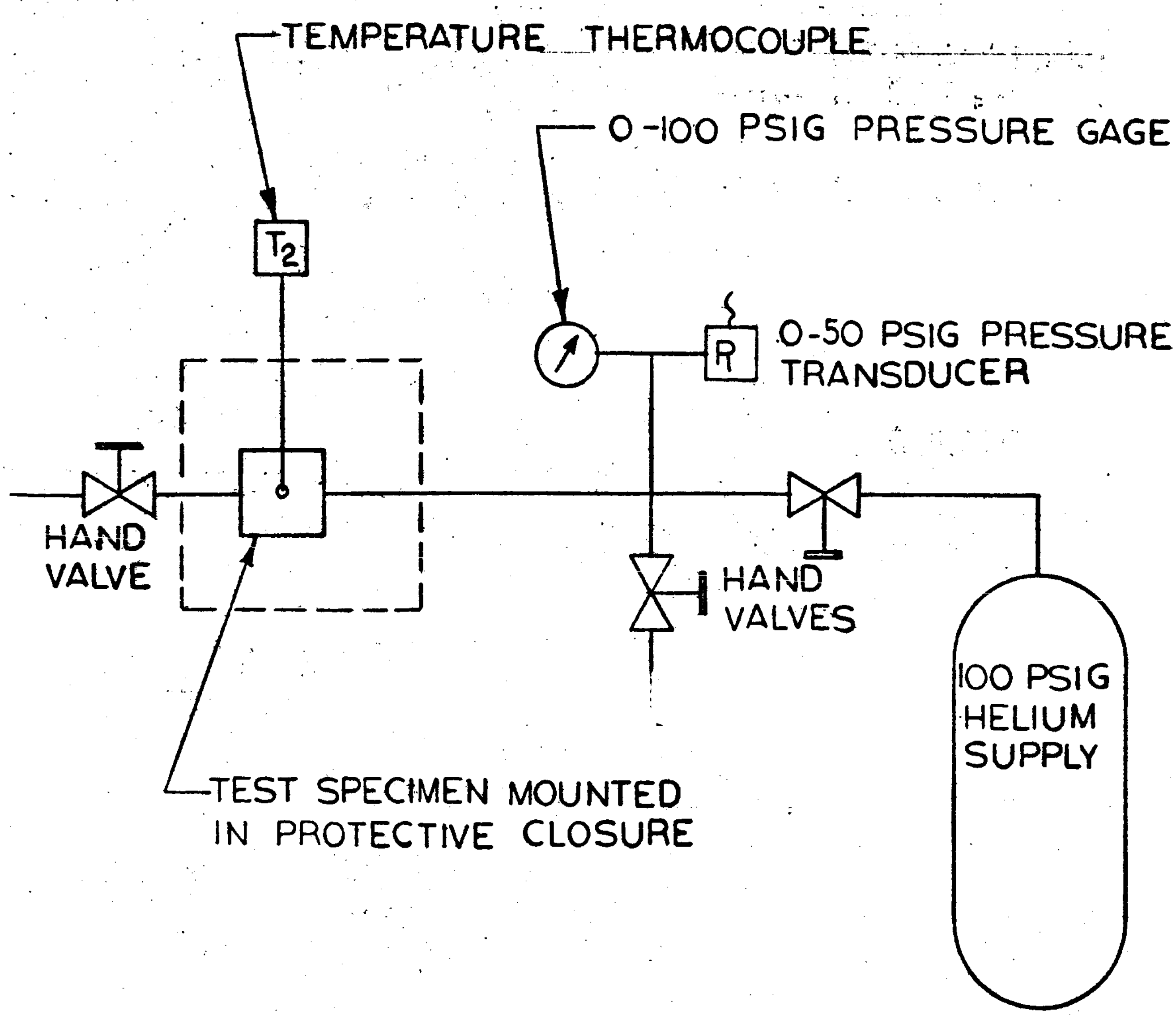
SCHEMATIC
ENDURANCE TEST
LIFE CYCLE PORTION

FIGURE VII



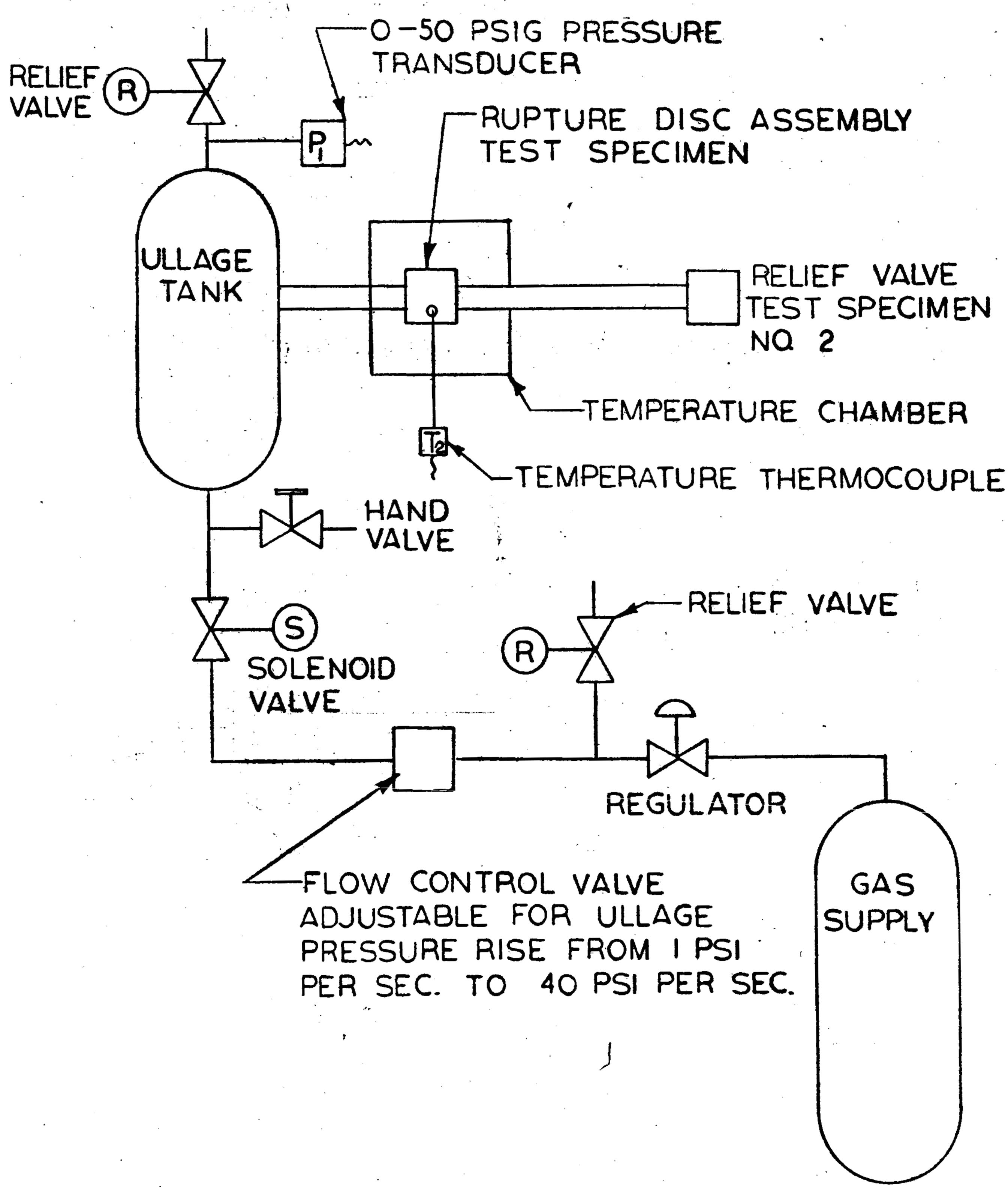
RELIEF VALVE AND RUPTURE DISC BURST TEST SCHEMATIC

FIGURE VIII



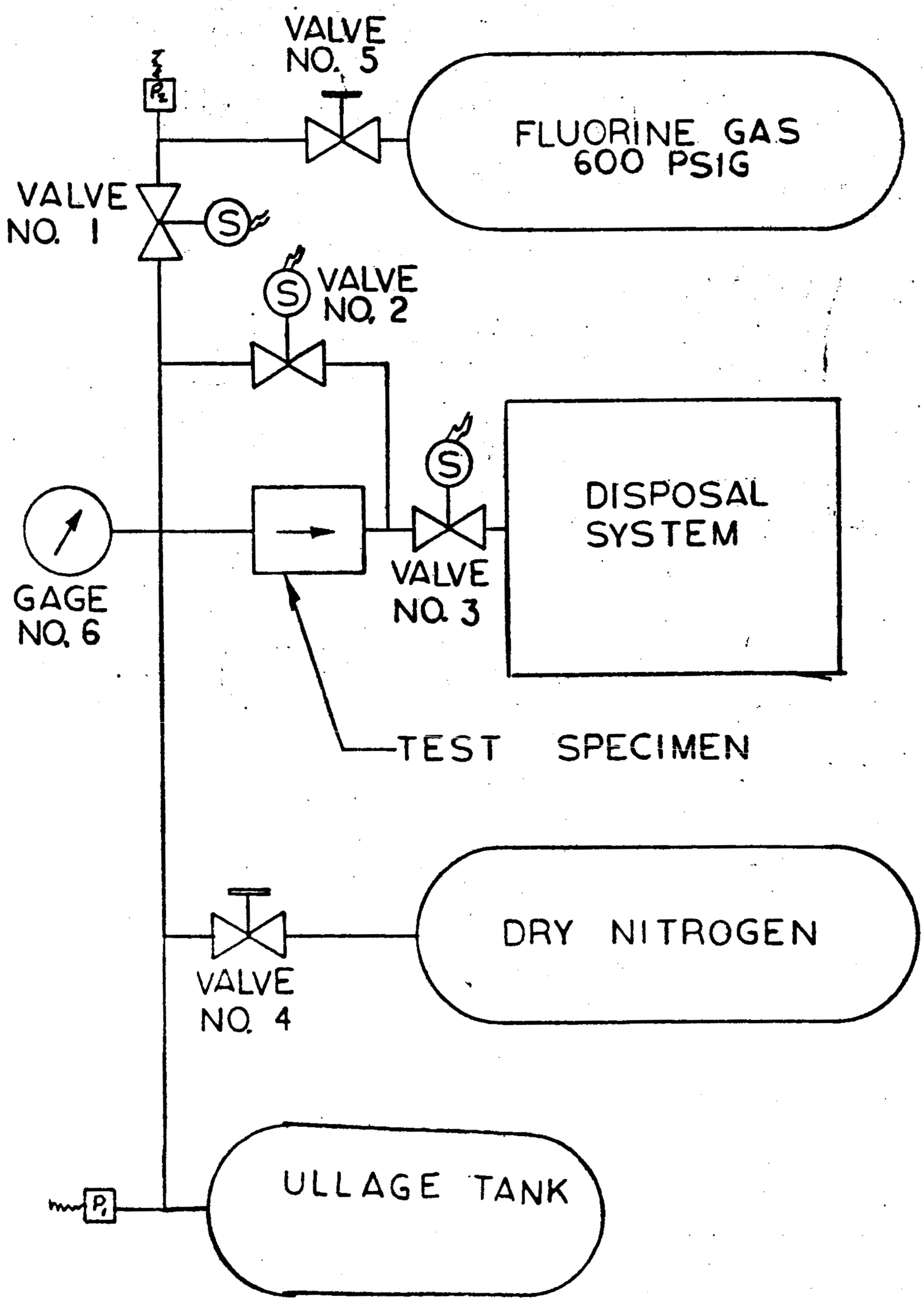
SCHEMATIC ENDURANCE TEST BURST PORTION

FIGURE IX



SCHEMATIC
RELIEF VALVE
FLUORINE COMPATIBILITY

FIGURE X



GENERAL DYNAMICS

Convair Division